Scaled momentum distributions for K_S^0 and $\Lambda/\bar{\Lambda}$

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DOI: `http://dx.doi.org/10.3204/DESY-PROC-2012-02/42`

Scaled momentum distributions for the strange hadrons K_S^0 and $\Lambda/\bar{\Lambda}$ were measured in deep inelastic ep scattering with the ZEUS detector at HERA using an integrated luminosity of 330 pb^{-1} in the kinematic region $10 < Q^2 < 40000$ GeV^2 and $0.001 < x < 0.75$. Predictions based on different approaches to fragmentation were compared to the measurements. Next-to-leading-order QCD calculations based on fragmentation functions, FFs, extracted from e^+e^- data alone, fail to describe the measurements. The measurements presented in this paper have the potential to further constrain the fragmentation functions of quarks, anti-quarks and gluons yielding K_S^0 and $\Lambda/\bar{\Lambda}$ strange hadrons.

1 Motivation

Perturbative QCD allows to calculate processes involving coloured partons. To compare to experimental results, one needs to take into account jet fragmentation and hadronization in order to predict final states consisting of colour-neutral hadrons. In Monte-Carlo(MC) models, this is usually done by using the Lund string model. The other method is to use fragmentation functions (FFs) within the standard framework of leading-twist collinear QCD factorization. In both cases, one needs to tune parameters to obtain a good desription of the data. This has been done extensively for inclusive charged-particle final-states using electron-positron, pp, $\bar{p}p$ and ep data. However, no attempt has been carried out so far to use a subset of strange hadrons for such a tuning.

The analysis presented in this talk is based on data from the HERA collider using the ZEUS detector. The ability of previously tuned MC models and of calculations using FFs to describe scaled momentum distributions for K_S^0 and $\Lambda/\bar{\Lambda}$ strange hadrons is tested. To this end, the data are compared to the color dipole model (CDM) of the Ariadne MC and to the matrix-element parton shower (MEPS) of the Lepto MC, as well as to the next-to-leading-order (NLO) calculations.

In this study, the scaled momentum distributions for K_S^0 and Λ hadrons[1] are presented for the first time in DIS. The scaled momentum is defined as $x_p = 2P^{\mathrm{Breit}}/\sqrt{Q^2}$, where P^{Breit} is the particle momentum in the Breit frame and Q^2 is the virtuality of the exchanged photon. The Breit frame [1] is the frame in which the exchanged virtual boson is purely space-like, with 3-momentum $\mathbf{q} = (0, 0, -Q)$. It provides a maximal separation between the products of the beam fragmentation and the hard interaction. The measurements were performed in the

[1] Here and in the following, the notation Λ includes both the particle and its antiparticle unless otherwise stated.

current region of the Breit frame, which is equivalent to one hemisphere in e^+e^- annihilations, as functions of Q^2 and x_p.

2 Experimental details

The data used in this analysis were collected during the running period 2005–2007, when HERA operated with protons of energy $E_p = 920$ GeV and electrons of energy $E_e = 27.5$ GeV, and correspond to an integrated luminosity of 330 pb^{-1}. The data passed through a standard neutral-current (NC) deep inelastic scattering (DIS) selection [6] in the kinematic region $10 < Q^2 < 40000$ GeV^2 and $0.001 < x < 0.75$, where x is the Bjorken scaling variable.

The strange hadrons K_S^0 and Λ were identified via the charged-decay channels $K_S^0 \to \pi^+\pi^-$ and $\Lambda \to p\pi^-$ ($\bar{\Lambda} \to \bar{p}\pi^+$). The candidates were reconstructed using two oppositely charged tracks associated with a displaced secondary vertex.

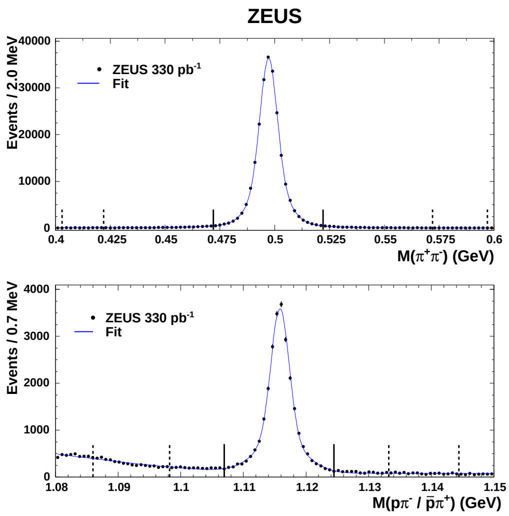

Figure 1: (a) The $\pi^+\pi^-$ invariant-mass distribution for K_S^0 candidates (dots). (b) The $p\pi^-/\bar{p}\pi^+$ invariant-mass distribution for $\Lambda/\bar{\Lambda}$ candidates (dots). In both (a) and (b), the solid line represents an indicative fit by two Gaussians and a (a) linear and (b) quadratic background function. The solid vertical lines indicate the signal window used in the analysis. The dashed lines indicate the two sideband regions used for the background subtraction in each kinematic bin.

Figure 1 shows the $M(\pi^+\pi^-)$ and $M(p\pi)$ distributions. A small amount of background is observed. The fit shown in Fig. 1 is for illustration only. The number of K_S^0 (Λ) candidates in each bin of x_p and Q^2 was estimated by counting the entries in the signal region, $472 - 522$ ($1107.0 - 1124.5$) MeV, and subtracting the number of expected background entries. The latter was determined from a linear fit to the sideband regions $403 - 422$ and $572 - 597$ ($1086.0 - 1098.2$ and $1133.2 - 1144.4$) MeV, also indicated in Fig. 1. There were 806 505 (165 875) K_S^0 (Λ) candidates in the data sample. In the current region of the Breit frame, there were 238 153 K_S^0 and 40 728 Λ candidates. A Monte Carlo study showed that 6% of the selected Λ candidates come from higher-baryon decays.

3 Comparison of the predictions with the data

Next-to-leading-order predictions, based on different FFs, and leading-logarithm parton-shower Monte Carlo calculations, interfaced with the Lund string fragmentation model, were compared to the measurements.

Two sets of calculations based on different parameterisations of the FFs were used. The first set was obtained from fits to e^+e^- data and based on the program CYCLOPS [2], called "AKK+CYCLOPS" [3, 4]. The second set was obtained from a global fit to e^+e^-, pp and ep data, called "DSS" [5]. It was only available for K_S^0 predictions.

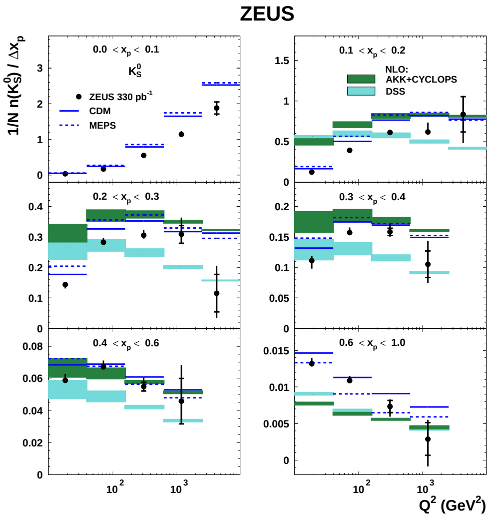

Figure 2: The measured scaled momentum distributions $(1/N)(n(K_S^0)/\Delta x_p)$ as functions of Q^2 in different regions of x_p (dots). For comparison, the NLO predictions of AKK+CYCLOPS (dark-shaded band) and DSS (light-shaded band) are also presented. The bands represent the theoretical uncertainty. The predictions from CDM (solid lines) and MEPS (dashed lines) are also shown.

Figure 2 shows the scaled momentum distributions for K_S^0 as functions of Q^2 in different regions of x_p. The data show clear scaling violation. This behaviour is expected on the basis of the QCD description of the parton evolution with increasing Q: the phase space for soft gluon radiation increases, leading to a rise of the number of soft particles with small x_p.

The predictions from the CDM and MEPS models, based on leading-logarithmic matrix elements plus parton shower and the Lund fragmentation model are compared to the measurements in Fig. 2. They describe the shapes of the distributions fairly well while overestimating the overall production of K_S^0 by 10 to 20%.

The NLO QCD calculations, based on full NLO matrix elements and the fragmentation-function approach are also compared to the measurements in Fig. 2 for $x_p > 0.1$. The AKK+CYCLOPS calculations, based on FFs extracted from e^+e^- data alone, fail to describe the measurements. These calculations predict a much too high K_S^0 rate but for $x_p > 0.6$. These discrepancies might come from the fact that the FFs used in these predictions have a poorly constrained gluon contribution, which is dominant at low x_p.

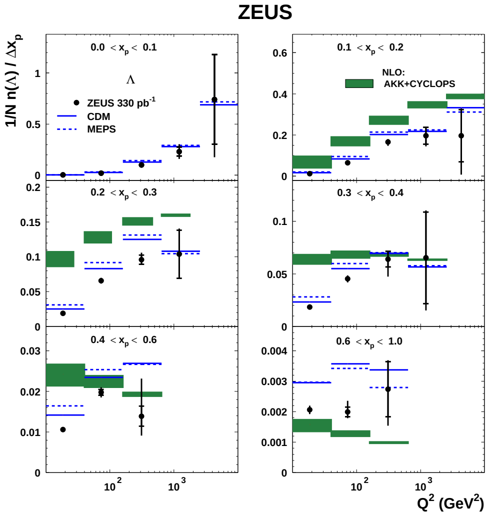

Figure 3: The measured scaled momentum distributions $(1/N)(n(\Lambda)/\Delta x_p)$ as functions of Q^2 in different regions of x_p (dots). Other details as in the caption to Fig. 2.

The DSS calculations, based on FFs extracted from a global analysis, give a good description of the measurements for $x_p > 0.3$ and $10 < Q^2 < 40000$ GeV^2. The prediction for this region of phase space is mainly constrained by *pp* data, which sufficiently constrain the FFs at high x_p. At lower x_p, the DSS calculations fail to describe the data. This can be explained by the fact that the DSS fit in this region of phase space is mostly unconstrained by the available data. Thus, the measurements presented in this paper will help to improve significantly such global fits in this region of phase space.

Figures 3 shows the scaled momentum distributions for Λ. Scaling violations are clearly observed. The predictions of CDM and MEPS give a reasonable description of the measurements, but overestimate the overall Λ rate by $\approx 20\%$. The AKK+CYCLOPS NLO calculations fail to describe the measurements.

ZEUS has previously published measurements of scaled momentum distributions for inclusive charged particles in DIS [6]. These measurements are dominated by the contribution from charged pions. Figure 4 shows the scaled momentum distributions presented in this paper together with those from the inclusive charged particles analysis in the kinematic region of $0.1 < x_p < 0.4$ as functions of Q^2. For $Q^2 > 100$ GeV^2, all distributions show a plateau. At lower Q^2, and especially at low x_p, sizeable mass effects are expected. This is clearly visible. For $0.1 < x_p < 0.2$, the value of $(1/N)(n(H)/\Delta x_p)$ drops to 10 (20)% of its maximum value for Λ (K^0_S), while for inclusive charged particles, the $(1/N)(n(H)/\Delta x_p)$ value is still 40% of the plateau value at the lowest Q^2 accessible.

4 Summary and conclusions

Scaled momentum distributions for K^0_S and Λ hadrons were measured for the first time in *ep* DIS. The distributions were measured in the Q^2 range from 10 to 40000 GeV^2 and $0.001 < x < 0.75$.

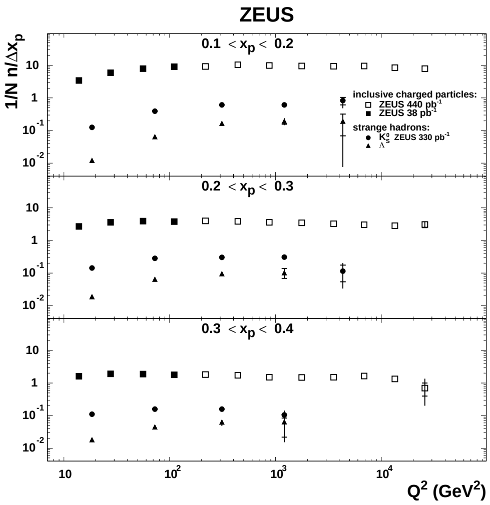

Figure 4: The measured scaled momentum distributions $(1/N)(n(H)/\Delta x_p)$ for $H = K^0_S$ (dots), Λ (triangles) and light charged particles (squares) as functions of Q^2 in different regions of x_p. Other details as in the caption to Fig. 2.

Scaling violations were clearly observed for both the K^0_S and Λ hadrons.

Next-to-leading-order QCD calculations, based on different parameterisations of the FFs, were compared to the measurements. The predictions based on FFs extracted from e^+e^- data alone fail to describe the measurements. Those predictions based on a global analysis which include e^+e^-, pp and ep data give an improved description of the measurements. However, they predict a too high production rate of K^0_S and Λ hadrons at low x_p and Q^2. The measurements presented in this paper have the potential to constrain significantly the FFs for the strange hadrons K^0_S and Λ.

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