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Strangeness Production in Deep-Inelastic ep Scattering at HERA§

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Abstract: The production of neutral strange hadrons is studied using deep-inelastic events measured with the H1 detector at HERA. The measurements of K_s^0 and $\Lambda(\bar{\Lambda})$ productions are made in two regions of phase space defined by the negative four-momentum transferred squared of the photon, $7 < Q^2 < 100 GeV^2$ and the inelasticity $0.1 < y < 0.6$ for the K_s^0 and $145 < Q^2 < 20000 GeV^2$ and $0.2 < y < 0.6$ for the Λ. K_s^0 and $\Lambda(\bar{\Lambda})$ production cross sections are determined. Differential ratios of K_s^0 production to charged hadron production are measured. Differential $\Lambda(\bar{\Lambda})$ yields per event are determined. The $\Lambda - \bar{\Lambda}$ asymmetry is measured and found to be consistent with zero. Predictions of leading order Monte Carlo programs are compared to data.

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1. INTRODUCTION

The measurement of strange particle production in high energy collisions provides valuable information for understanding Quantum Chromodynamics (QCD) in the perturbative and non-perturbative regime. In neutral current deep-inelastic *ep* scattering (DIS) at HERA four different processes depicted in Fig. (**1**) contribute to strange hadron production.

Strange quarks may originate directly from the strange sea of the proton (Fig. **1a**), from boson-gluon-fusion (BGF, Fig. **1b**), from the decays of heavy flavoured hadrons (Fig. **1c**) and from the creation of $s\bar{s}$ pairs in the non-perturbative fragmentation process (Fig. **1d**). The latter process is the dominant source for strange hadron production. In the modelling of the fragmentation process the suppression of $s\bar{s}$ pairs due to the mass of the strange quark is generally controlled by the strangeness suppression factor λ_s [1, 2]. Especially, the ratio of K_s^0 to charged particles should strongly depends on this quark mass effect.

This paper presents new measurements of K_s^0 production at low Q^2 and Λ production at high Q^2. Results are presented on K_s^0 and Λ production cross sections, on the ratio of K_s^0 production to charged particles production measured in the same phase space region, on Λ yields normalised to DIS cross sections, and on the Λ -- $\bar{\Lambda}$ asymmetry. The measurements are shown as a function of several observables characterising the DIS kinematics and the strange particles production dynamics in the laboratory frame. The results are compared with predictions obtained from leading order Monte Carlo calculations, based on matrix elements with parton shower simulation. The rôle of strangeness suppression on hadrons with strangeness is investigated.

2. SELECTION OF HADRON CANDIDATES

The data used in the analyses correspond to an integrated luminosity of $109\,pb^{-1}$ in case of K_s^0 production and $340\,pb^{-1}$ in case of Λ production and were collected with the H1 detector [3] in the years 2004 to 2007 when protons with an energy of 920 GeV collided with electrons[1] with an energy of 27.6 GeV producing a centre-of-mass energy of $\sqrt{s} = 319\ GeV$. The kinematics of the scattering process at HERA are described using the Lorentz invariant variables Q^2 denoting the square of the photon virtuality, the inelasticity in the proton rest frame y and Bjorken scaling variable x. At fixed $\sqrt{s}$ only two of these variables are independent because of $Q^2 = xys$. The following kinematic ranges are used in the analyses: $7 < Q^2 < 100 GeV^2$ and $0.1 < y < 0.6$ for the K_s^0 and $145 < Q^2 < 20000 GeV^2$ and $0.2 < y < 0.6$ for the Λ (see Table **1**).

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[1]In this paper "electron" is used to denote both electron and positron.

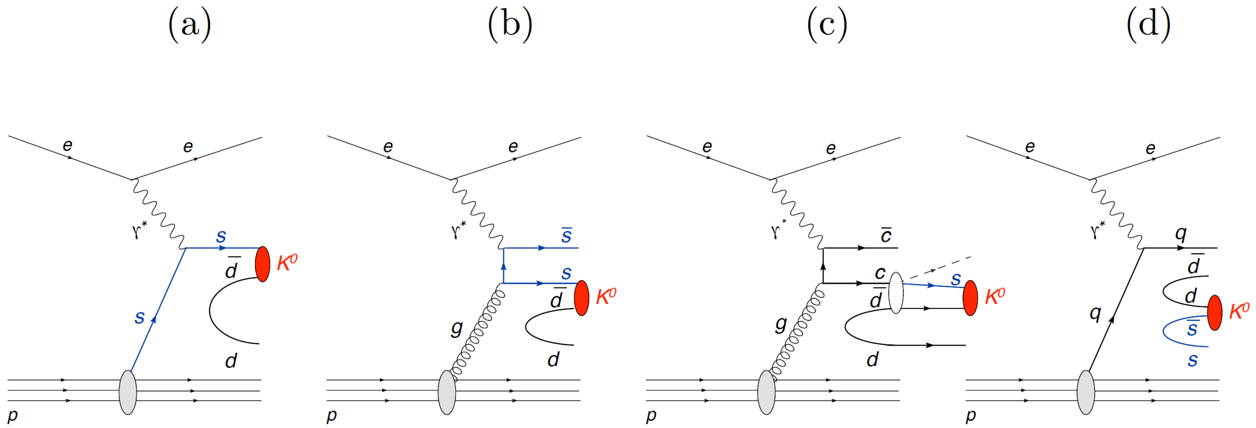

Fig. (1). Schematic diagrams for the processes contributing to strangeness production in ep scattering: (**a**) direct production from the strange sea, (**b**) BGF, (**c**) heavy hadron decays and (**d**) fragmentation. The diagrams relevant for K^0 production are shown.

The K_s^0 mesons and Λ baryons[2] are measured by the kinematic reconstruction of their decays $K_s^0 \to \pi^+\pi^-$ and $\Lambda \to p\pi^-$, respectively. The number of K_s^0 mesons and Λ baryons is obtained by fitting the invariant mass spectra with the sum of a signal and background function. For the signal function the skewed t-student function is used while the background shape is described by a threshold function with exponential damping. In total approximately 290000 K_s^0 mesons and 7000 $\Lambda(\bar{\Lambda})$ baryons are reconstructed in the phase space given in Table **1**. The fitted K_s^0 and Λ masses agree with the world average [4].

Table 1. Phase Space Regions Explored in the Analyses of K_s^0 and Λ Production, Respectively

DIS Kinematics	
K_s^0	$7 < Q^2 < 100 GeV^2$, $0.1 < y < 0.6$
Λ	$145 < Q^2 < 20000 GeV^2$, $0.2 < y < 0.6$
Hadron Kinematics	
K_s^0	$0.5 < p_T < 3.5\text{GeV}$, $-1.3 < \eta < 1.3$
Λ	$p_T > 0.3\text{GeV}$, $-1.5 < \eta < 1.5$

3. RESULTS AND DISCUSSION

3.1. Inclusive Cross Sections

The visible inclusive production cross sections σ_{vis} measured in the kinematic region defined in Table **1**, are $\sigma_{vis}(ep \to eK_s^0 X) = 10.66 \pm 0.02(stat.)^{+9.4}_{-8.5}(syst.)nb$, $\sigma_{vis}(ep \to e\Lambda X) = 144.7 \pm 0.04(stat.)^{+9.4}_{-8.5}(syst.)pb$ using a strangeness suppression factor of $\lambda_s = 0.286$ the models RAPGAP [5] and DJANGOH [6] predict K_s^0 cross sections of 10.93 nb and 9.88 nb, respectively, in reasonable agreement with the measurement. The cross section predictions for $\Lambda + \bar{\Lambda}$ production from the MEPS and CDM [7] models are shown in Table **2** for two values of the strangeness suppression parameter λ_s . The measured inclusive $\Lambda + \bar{\Lambda}$ cross section is close to the CDM prediction with $\lambda_s = 0.22$ and to the MEPS prediction with $\lambda_s = 0.286$.

[2]Unless otherwise noted, charge conjugate states are always implied.

Table 2. Monte Carlo Predictions for Different Settings of the Strangeness Suppresion Factor λ_s

	$\lambda_s = 0.220$	$\lambda_s = 0.286$
$\sigma_{vis}(ep \to e[\Lambda + \bar{\Lambda}]X)$ CDM	136 pb	161 pb
$\sigma_{vis}(ep \to e[\Lambda + \bar{\Lambda}]X)$ MEPS	120 pb	144 pb

3.2. Differential Cross Sections

Differential cross sections of K_s^0 and Λ production are shown in Figs. (**2a**, **b**, **3a**) as a function of Q^2, and as a function of the kinematic variable of the neutral strange hadrons in the laboratory frame, η along with the predictions of the MEPS and CDM models. The cross sections fall rapidly as Q^2 grows. The figures also include the ratios of predicted to measured cross sections for a better shape comparison. Apart from small normalisation differences the models describe the shapes of the measured cross sections as a function of Q^2 and η reasonably well.

3.3. Ratio of K_s^0 Production to Charged Particle Production

By normalising the K_s^0 production cross section to the cross section of charged particle production many model dependent uncertainties, like the cross section dependence on proton PDFs, cancel thus enhancing the sensitivity to details

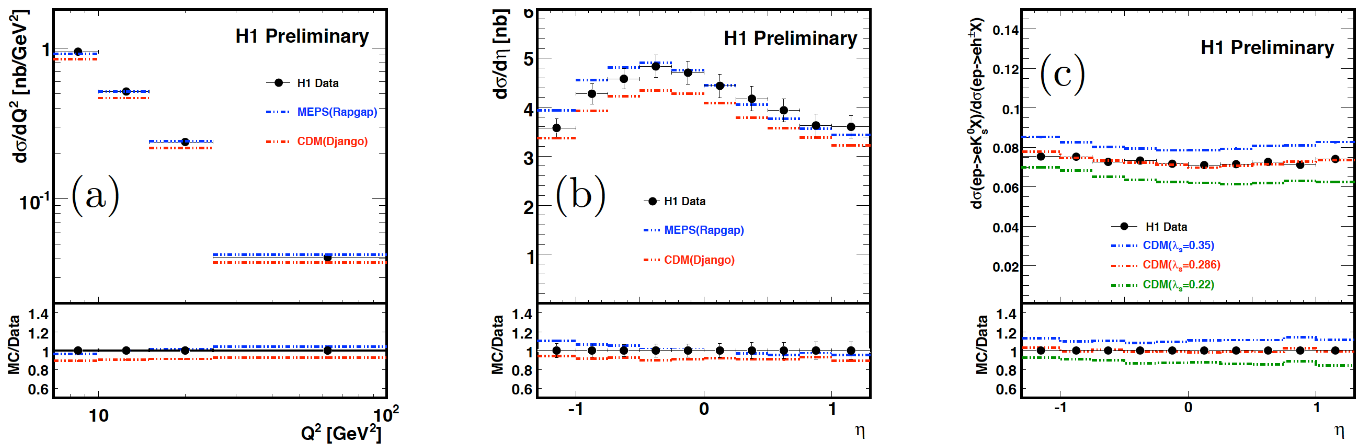

Fig. (2). Differential K_s^0 production cross sections as a function of (**a**) the photon virtuality squared Q^2, (**b**) its pseudorapidity η and (**c**) ratio of K_s^0 to charged particle production as a function of η in comparison to RAPGAP (MEPS) and DJANGOH (CDM). The inner (outer) error bars show the statistical (total) errors. The ratios "MC/Data" are shown for the different Monte Carlo predictions. For comparison, the data points are put to one.

of the fragmentation process. In Fig. (**2c**) the ratio of K_s^0 production to the cross section charged particle procduction is shown as a function of η in comparison to the expectations from DJANGOH using three different values of λ_s ranging from 0.220 to 0.35. The ratio in η is well described by the model in shape and a high sensitivity on λ_s is observed in the absolute value of this ratio, demonstrating the clear potential of using this ratio for extracting the strangeness suppression factor λ_s.

3.4. Λ Production to DIS Cross Section Ratio

In Fig. (**3b**) the ratio of Λ production to DIS cross section is shown as a function of Q^2 in comparison to the expectations from RAPGAP and DJANGOH both using $\lambda_s = 0.286$ and $\lambda_s = 0.220$. The DJANGOH prediction with $\lambda_s = 0.286$ yields the worst description of the data by overshooting them significantly independent of Q^2. For the same strangeness suppression factor also RAPGAP tends to yield ratios larger than observed in data for $Q^2 < 200$ GeV ^{2}. The best description is provided by DJANGHO using $\lambda_s = 0.220$.

3.5. Λ -- Λ Asymmetries

The Λ -- $\bar{\Lambda}$ asymmetry is defined as:

$$A_\Lambda = \frac{\sigma_{vis}(ep \to e\Lambda X) - \sigma_{vis}(ep \to e\bar{\Lambda}X)}{\sigma_{vis}(ep \to e\Lambda X) + \sigma_{vis}(ep \to e\bar{\Lambda}X)}. \quad (1)$$

This observable could shed light on the mechanism of baryon number transfer in *ep* scattering. A significant positive asymmetry would be an indication for the baryon

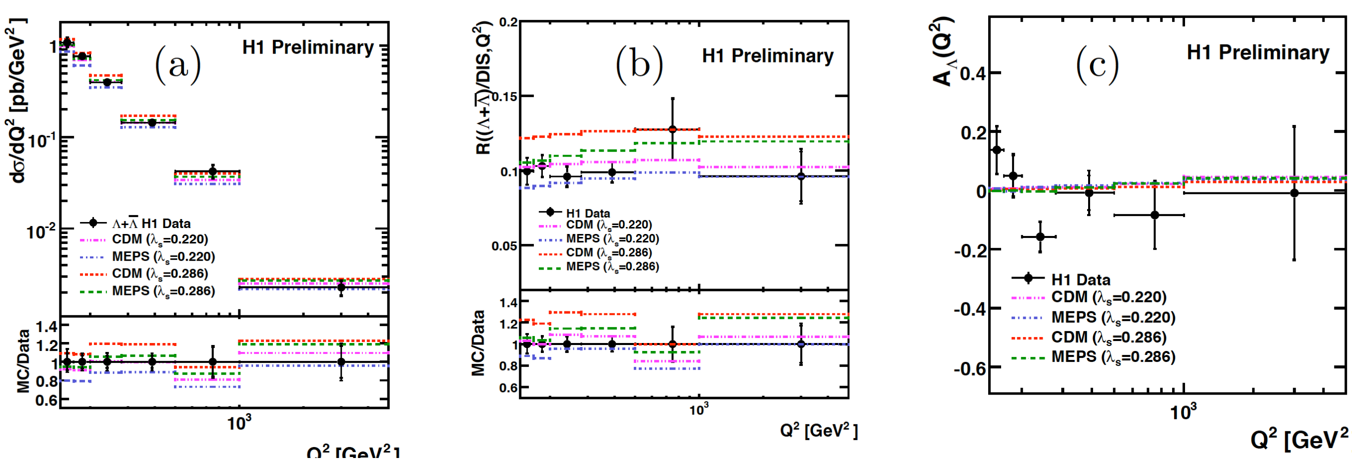

Fig. (3). The Q^2 dependence of (**a**) differential Λ production cross section, (**b**) ratio R(DIS) of Λ production to DIS cross section and (**c**) asymmetry A_Λ in comparison to RAPGAP (MEPS) and DJANGOH (CDM) with two different values of λ_s. The inner (outer) error bars show the statistical (total) errors. The "MC/Data" ratios are shown for different Monte Carlo predictions. For the ratios the data points are put at one for comparison.

number transfer from the proton to the Λ baryon. If present such an effect should be more pronounced in the positive η region in the laboratory frame. For the kinemaic region defined in table 1 the asymmetry is measured to be

$A_\Lambda = 0.002 \pm 0.022(stat.) \pm 0.018(syst.)$.

In Fig. (**3c**) the asymmetry A_Λ is shown as a function of Q^2. The data show no evidence for a non-vanishing asymmetry in the phase space region investigated.

4. CONCLUSIONS

This paper presents a study of inclusive production of K_s^0 and Λ in DIS at low Q^2 and high Q^2 measured with the H1 detector at HERA. The cross sections of K_s^0 and Λ production are measured as a function of the DIS kinematic variable Q^2 and of strange hadron production variables in the laboratory frame. In addition results on the ratio of K_s^0 production cross section to the charged particle cross section, the Λ production to DIS cross section ratio and the $\Lambda - \overline{\Lambda}$ asymmetry are presented. The measurements are compared to model predictions of DJANGOH, based on the colour-dipol model (CDM) and RAPGAP based on DGLAP matrix element calculations supplemented with parton showers (MEPS). Within the uncertainties both models provide a reasonable description of the data. The sensitivity of the ratio of K_s^0 to charged particle production cross sections on the strangeness suppression factor λ_s is demonstrated, however, a detailed understanding of concurrent processes of K_s^0 production is mandatory prior to the determination of λ_s. The measured visible Λ cross section is found to be described best by the CDM using $\lambda_s = 0.220$ and the MEPS model using $\lambda_s = 0.286$. When investigating the Λ production to DIS cross section ratio the best agreement is observed for the CDM with $\lambda_s = 0.220$. The $\Lambda - \overline{\Lambda}$ asymmetry is found to be consistent with zero.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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