Measurements of $K^{\pm}$, K^0_S, Λ and $\bar{\Lambda}$ and Bose-Einstein Correlations between Kaons at ZEUS

B.B. Levchenko *
(On behalf of the ZEUS Collaboration)

Moscow State University, Skobeltsyn Institute of Nuclear Physics
119991 Moscow, Russian Federation

Measurements of production of the neutral and charged strange hadrons in $e^{\pm}p$ collisions with the ZEUS detector are presented. The data on differential cross sections, baryon-to-meson ratios, baryon-antibaryon asymmetry and Bose-Einstein correlations in deep inelastic scattering and photoproduction are summarized [1].

1 Introduction

After pions, strange hadrons are most copiously produced particles in $e^{\pm}p$ collisions with a centre-of-mass energy of 318 GeV at HERA. In phenomenological models based on the Lund string scheme [2], an intensity of strange quark production is regulated by a free parameter λ_s, which has a value in the range from 0.2 to 0.4 for different processes.

The experimental results on $K^{\pm}$, K^0_S, Λ, and $\bar{\Lambda}$ production [3, 4] presented in this note are based on a data sample of $121\,\mathrm{pb}^{-1}$ collected by the ZEUS experiment at HERA. This is about 100 times larger data sample than used in previous HERA publications and extend the kinematical region of the measurements, thereby providing a tighter constraint on models.

2 Measurements of K^0_S, Λ and $\bar{\Lambda}$

Weak decaying neutral K^0_S and Λ are well reconstructed in the modes $K^0_S \to \pi^+\pi^-$, $\Lambda \to p\pi^-$, $\bar{\Lambda} \to \bar{p}\pi^+$ via displaced secondary vertices. The measurements have been performed in three different regions of Q^2: deep inelastic scattering (DIS) with $Q^2 > 25\,\mathrm{GeV}^2$; DIS with $5 < Q^2 < 25\,\mathrm{GeV}^2$; and photoproduction (PHP), $Q^2 \simeq 0\,\mathrm{GeV}^2$. In the PHP sample, two jets, each of at least 5 GeV transverse energy, were required.

Spectra of K^0_S and $\Lambda + \bar{\Lambda}$ in DIS. Measured differential cross sections are shown in Fig. 1. The cross sections are compared to the absolute predictions of ARIADNE 4.12 [5] and LEPTO 6.5 [6] MC calculations. The ARIADNE program with $\lambda_s = 0.3$ describes the $\Lambda + \bar{\Lambda}$ data reasonably well in both Q^2 samples. The description of the data on the lighter strange meson K^0_S by ARIADNE is less satisfactory. The slope of the P_T^{LAB} dependence is incorrect and in the high-Q^2 domain the data already requires $\lambda_s < 0.3$. The cross section at low x_{Bj} is underestimated for both low- and high-Q^2 samples [3]. The LEPTO MC does not describe the data well and predicts too fast grow of the cross sections with Q^2. We conclude, that in production of baryons the data requers λ_s to be approximately constant but in K^0_S production λ_s have to decrease with Q^2.

Baryon-antibaryon asymmetry in DIS and PHP. A positive asymmetry of 3.5% is predicted in DIS [7], due to the so called gluon-junction mechanism that makes it possible

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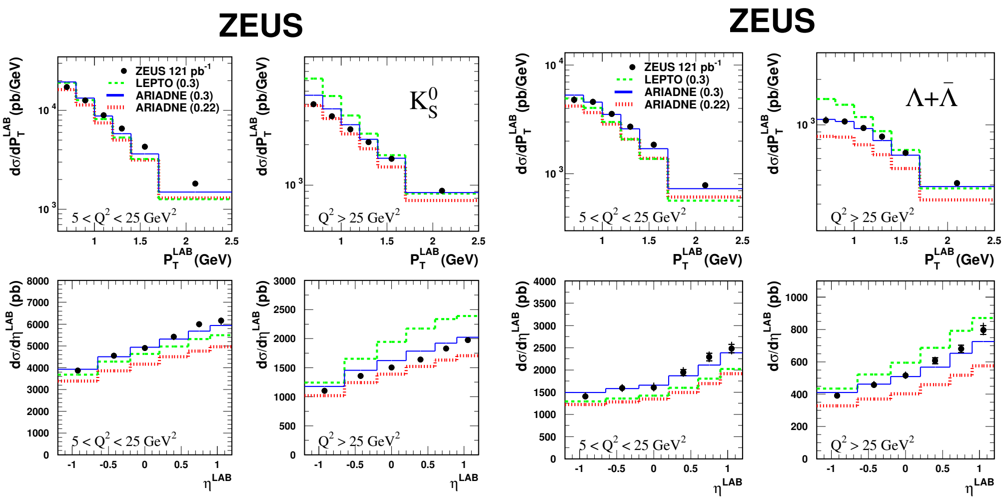

Figure 1: Differential K^0_S and $\Lambda + \bar{\Lambda}$ production cross-sections. The model predictions are at values of a strangeness suppression factor λ_s shown in parenthesis.

for the *baryon number to travel* several units of rapidity, in this case from the proton beam direction to the rapidity around 0 in the laboratory frame.

The baryon-antibaryon asymmetry $\mathcal{A} = (N(\Lambda) - N(\bar{\Lambda}))/(N(\Lambda) + N(\bar{\Lambda}))$ has been measured and compared to MC predictions from ARIADNE, LEPTO and PYTHIA [8]. The following values were obtained: $\mathcal{A} = 0.3 \pm 1.3^{+0.5}_{-0.8}\%$ at high Q^2 and have to be compared to the ARIADNE ($\lambda_s = 0.3$) prediction of $0.4 \pm 0.2\%$; in PHP $\mathcal{A} = -0.07 \pm 0.6^{+1.0}_{-1.0}\%$, compared to the PYTHIA prediction of $0.6 \pm 0.1\%$.

Figure 2 shows $\mathcal{A}$ at high-Q^2 and in PHP. In all cases, $<\mathcal{A}>$ is consistent both with no asymmetry and consistent with the very small asymmetry predicted by Monte Carlo. However, as shown in Figs 2, in DIS the baryon-antibaryon asymmetry became positive and increases in the incoming proton hemisphere ($\eta^{LAB} > 0$), as well as at P_T^{LAB} below 1 GeV.

Baryon-to-meson ratio in photoproduction. The relative yield of strange baryons and mesons was studied with the ratio $\mathcal{R} = (N(\Lambda) + N(\bar{\Lambda}))/N(K^0_S)$. Figure 3 shows $\mathcal{R}$ for the PHP sample. For the direct-enriched sample, where $x_\gamma^{\mathrm{OBS}} > 0.75$, $\mathcal{R}$ is about 0.4, the same value as in DIS at low x_{Bj} and low Q^2 [3]. However, $\mathcal{R}$ rises to a value of about 0.7 towards low x_γ^{OBS} (resolved-enriched sample), while it stays flat in the PYTHIA prediction.

In order to study this effect further, the PHP events were divided into two samples . In the first, called *fireball-enriched*, the jet with the highest transverse energy was required to contribute at most 30% to the total hadronic transverse energy. The other sample, containing all the other events, was called *fireball-depleted*. The measured $\mathcal{R}$ (see Fig. 3, Right:) is larger for the fireball-enriched sample, most significantly at high P_T^{LAB}, than it is for the fireball-depleted sample. This feature is not reproduced by PYTHIA, which predicts almost the same $\mathcal{R}$ for both samples. The PYTHIA prediction reasonably describes the measured values of $\mathcal{R}$ for the fireball-depleted sample. This is not surprising as PYTHIA generates jets in events according to the multiple interaction mechanism, which makes several independent jets, like those in DIS or e^+e^- where baryons and mesons are created locally.

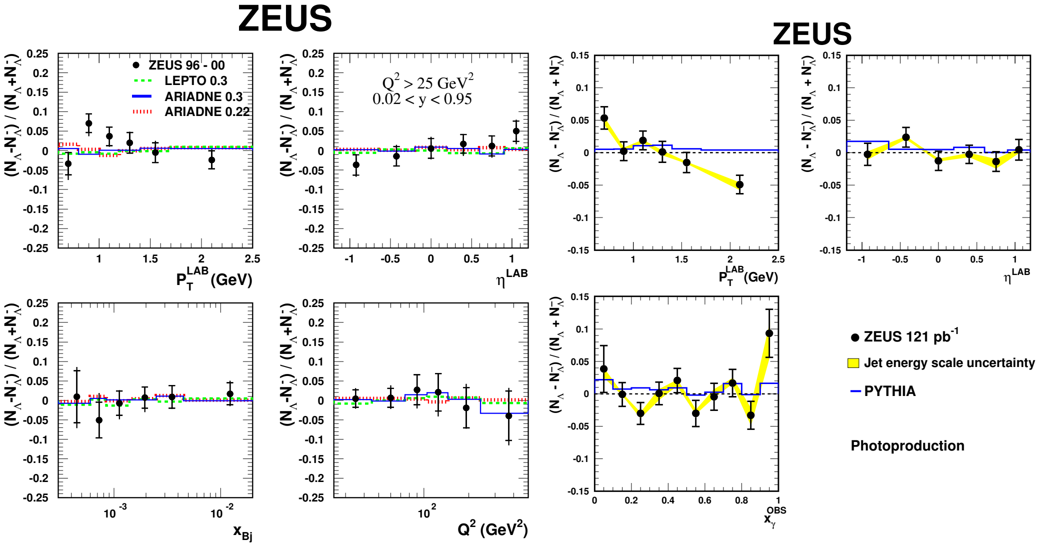

Figure 2: The baryon-antibaryon asymmetry $\mathcal{A}$ as a function of P_T^{LAB}, η^{LAB}, Q^2, $x_{\rm Bj}$ and $x_\gamma^{\rm OBS}$. Left: in the DIS high-Q^2 sample. Right: The photoproduction sample with the predictions from PYTHIA for $\lambda_s = 0.3$.

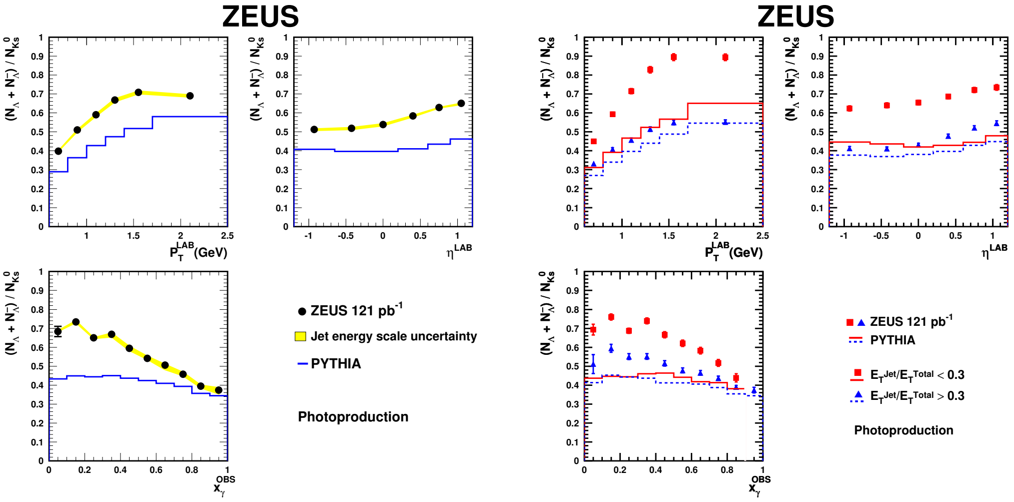

Figure 3: The ratio $\mathcal{R}$ as a function of P_T^{LAB}, η^{LAB}, and $x_\gamma^{\rm OBS}$ for the PHP events. Left: The ratio from the normal PHP sample. Right: The ratio from the fireball-enriched (squares) and the fireball-depleted (triangles) samples. The predictions from PYTHIA for $\lambda_s = 0.3$.

We note that the increase of the ratio $\mathcal{R}$ toward the proton hemisphere, reflects a rapid grow of the $\Lambda + \bar\Lambda$ cross section as η^{LAB} increases, as compared to the K_S^0 cross section grow [3].

3 Bose-Einstein correlations of charged and neutral kaons in DIS

Primordial quantum correlations between identical bosons, so-called Bose-Einstein correlations (BEC), so far is only the method to estimate the space-time geometry of an elementary particle emission source. The measurements of the radius of the emission source have been mostly performed with pure quantum states $\pi^{\pm}$, $K^{\pm}$, $p/\bar{p}$. For mixed quantum states, like K^0_S, the information is scare.

The results presented below were obtained with charged kaons selected using the energy-loss measurements, dE/dx. The identification of $K^{\pm}$ is possible for $p < 0.9\,\mathrm{GeV}$. The resulting data sample contained 55522 $K^{\pm}K^{\pm}$ pairs. The K^0_S mesons were identified via displaced secondary vertices. After all cuts, the selected data sample contained 18405 $K^0_S K^0_S$ pairs and 364 triples [4].

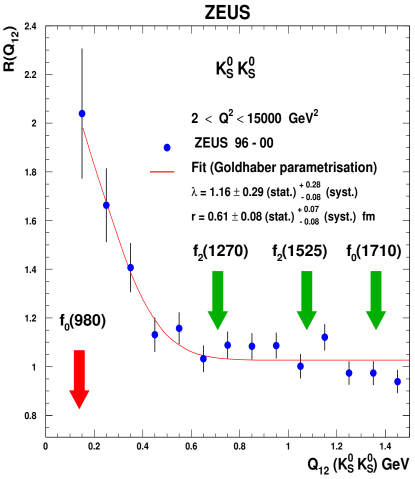

Figure 4: The two-particle correlation functions at $<Q^2>= 35\,\mathrm{GeV}^2$ for neutral kaons with fits to the Goldhaber function. Arrows indicates Q_{12} regions with contributions from resonances in the $K^0_S K^0_S$ system.

Figure 4 shows the two-particle correlation function $R(Q_{12})$ for identical kaons calculated using the double ratio method $R(Q_{12}) = R_{data}(Q_{12})/R_{MC}(Q_{12})$, where $R_{data}(Q_{12})$ is the ratio of the two-particle densities constructed from pairs of kaons coming from the same and different events. $R_{MC}(Q_{12})$ is obtained in similar way for Ariadne MC events without BEC. Q_{12} is given by $Q_{12} = \sqrt{-(p_1 - p_2)^2}$. Assuming a Gaussian shape of emission source, $R(Q_{12})$ were fitted by the standard Goldhaber-like function $R(Q_{12}) = \alpha(1 + \lambda \exp(-Q_{12}^2 r^2))$ to extract the degree of the source coherence λ and the source radius r. The measured radii for $K^{\pm}K^{\pm}$ and $K^0_S K^0_S$ are close to each other [4]. In case of $K^0_S K^0_S$, the fit (see Fig. 4) does not take into account a possible contamination from the scalar $f_0(980)$ decaying below the threshold. The most probable fraction of $f_0(980)$ which allows describe the excess of data over MC was estimated to be 4%. The results corrected for the f_0 contamination are $\lambda = 0.70 \pm 0.19^{+0.47}_{-0.53}$ and $r = 0.63 \pm 0.09^{+0.11}_{-0.08}$ fm. Thus, the $f_0(980) \to K^0_S K^0_S$ decay can significantly affect the λ parameter for $K^0_S K^0_S$ correlations. The radius values obtained in DIS agrees with e^+e^- annihilation results at LEP [4].

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