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

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Abstract

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 the 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 [5, 6] 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 $5\,\mathrm{GeV}$ transverse energy, were required.

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2.1 Spectra of K_S^0 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 [7] and LEPTO 6.5 [8] 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 K_S^0 data by ARIADNE is less satisfactory. The slope of the $P_T^{\rm LAB}$ dependence is incorrect and in the high-Q^2 domain the data requires $\lambda_s < 0.3$. The cross section at low $x_{\rm Bj}$ (not shown) is underestimated for both the low- and the high-Q^2 samples [3]. The LEPTO MC does not describe the data well and predicts a too fast grow of the cross sections with Q^2. We conclude, that for the production of baryons the data reqiuers λ_s to be approximately constant, but in case of K_S^0 production λ_s has to decrease with Q^2.

2.2 Baryon-antibaryon asymmetry in DIS and PHP

A positive asymmetry of 3.5% is predicted in DIS [9], due to the so-called gluon-junction mechanism that makes it possible 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

$$\mathcal{A} = \frac{N(\Lambda) - N(\bar{\Lambda})}{N(\Lambda) + N(\bar{\Lambda})}$$

has been measured and compared to MC predictions from ARIADNE, LEPTO and PYTHIA [10]. The following value was obtained at high Q^2 : $\mathcal{A} = 0.3 \pm 1.3^{+0.5}_{-0.8}\%$ which has 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 with a very small asymmetry predicted by the Monte Carlo. However, as shown in Figs 2, in DIS the baryon-antibaryon asymmetry becomes positive and increases in the incoming proton hemisphere ($\eta^{LAB} > 0$), as well as at P_T^{LAB} below 1 GeV.

2.3 Baryon-to-meson ratio in photoproduction

The relative yield of strange baryons and mesons was studied with the ratio

$$\mathcal{R} = \frac{N(\Lambda) + N(\bar{\Lambda})}{N(K_S^0)}.$$

Figure 3 shows $\mathcal{R}$ for the PHP sample. For the direct-enriched sample, where $x_\gamma^{\rm OBS} > 0.75$, $\mathcal{R}$ is about 0.4, the same value as in DIS at low $x_{\rm Bj}$ and low Q^2 [3]. However, $\mathcal{R}$ rises to a value of about 0.7 towards low $x_\gamma^{\rm OBS}$ (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, Bottom) is larger for the fireball-enriched sample, most significantly at high $P_T^{\rm LAB}$, 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.

We note that the increase of the ratio $\mathcal{R}$ toward the proton hemisphere, reflects a rapid growth of the $\Lambda + \bar{\Lambda}$ cross section as η^{LAB} increases, as compared to the K^0_S 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 the only 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 $p < 0.9\,\text{GeV}$. 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 shows the two-particle correlation function $R(Q_{12})$ for identical kaons calculated using the double ratio method

$$R(Q_{12}) = \frac{R_{data}(Q_{12})}{R_{MC}(Q_{12})},$$

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 a 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

$$R(Q_{12}) = \alpha(1 + \lambda\, e^{-Q_{12}^2 r^2})$$

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 to 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 agree with e^+e^- annihilation results at LEP [4].

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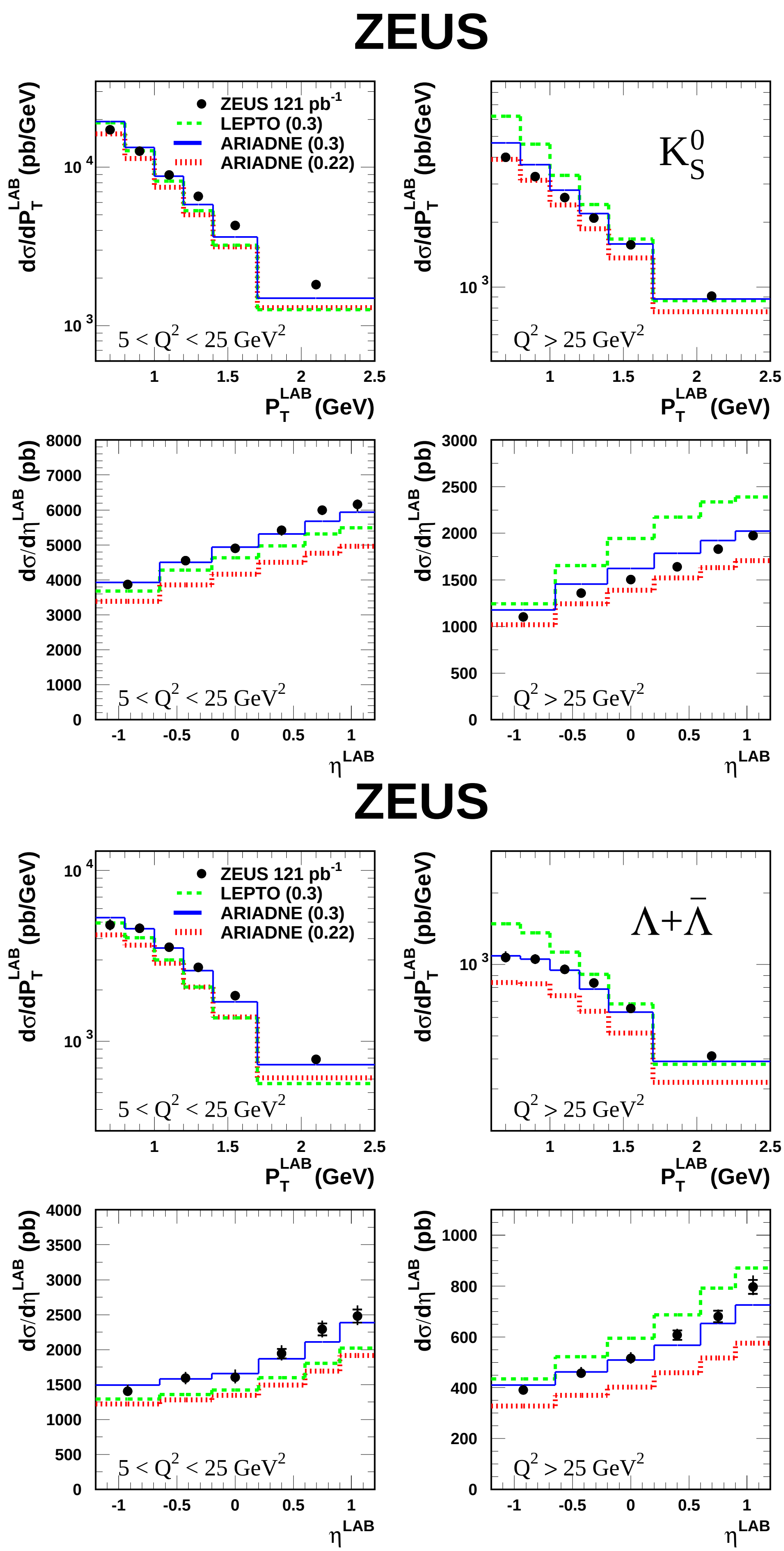


Figure 1: Differential K_s^0 and $\Lambda + \bar{\Lambda}$ production cross-sections. The model predictions are at values of a strangeness suppression factor λ_s shown in paranthesis.

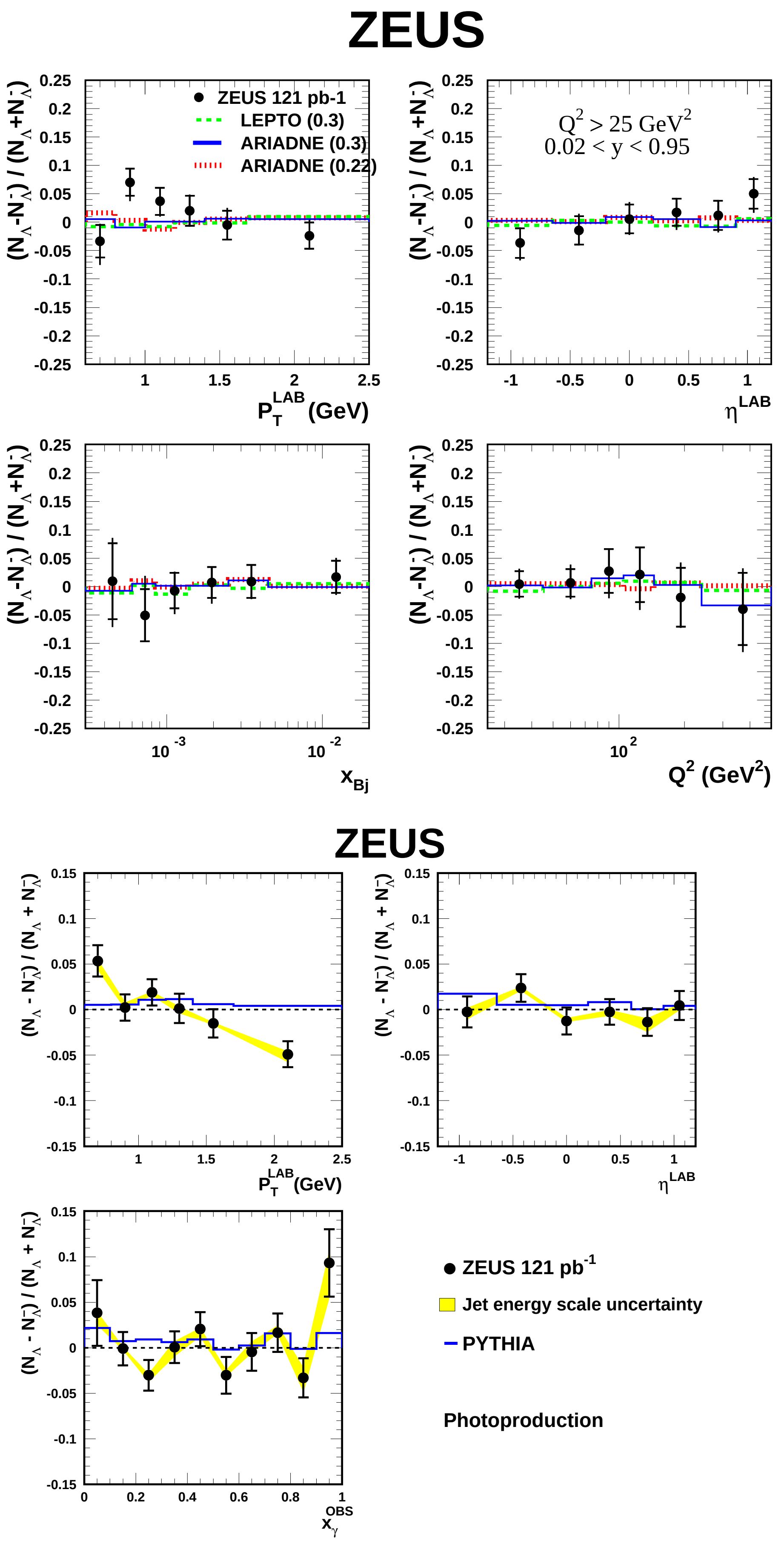
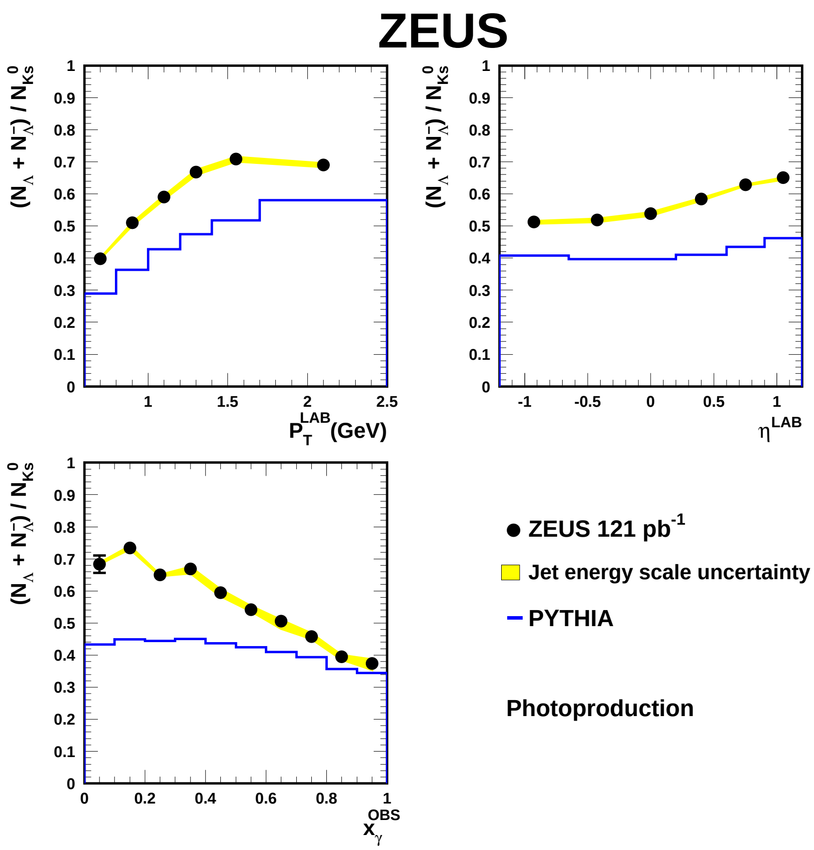


Figure 2: The baryon-antibaryon asymmetry $\mathcal{A}$ as a function of $P_T^{\rm LAB}$, $\eta^{\rm LAB}$, $x_{\rm Bj}$ and Q^2 for the DIS sample (top), and as a function of $P_T^{\rm LAB}$, $\eta^{\rm LAB}$ and $x_\gamma^{\rm OBS}$ for the photoproduction sample (bottom). The different lines are the predictions of the different MC generators, as indicated in the plots.



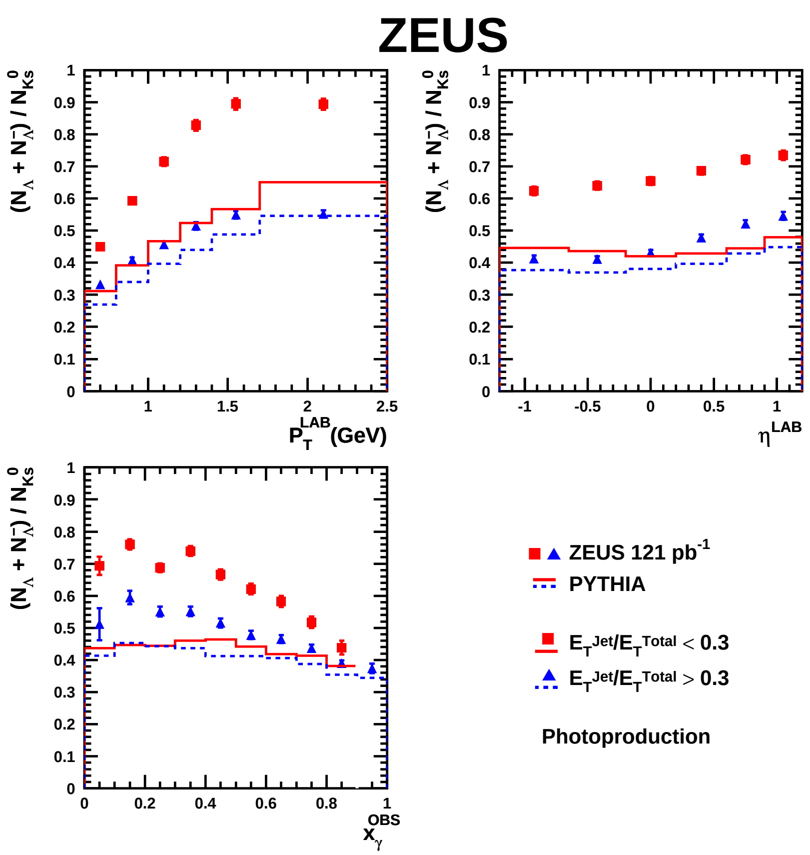


Figure 3: The ratio $\mathcal{R}$ as a function of P_T^{LAB}, η^{LAB}, and $x_\gamma^{\rm OBS}$ for the PHP events. Top: the ratio from the whole PHP sample. Bottom: the ratio from the fireball-enriched (squares) and the fireball-depleted (triangles) samples. The predictions from PYTHIA for $\lambda_s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

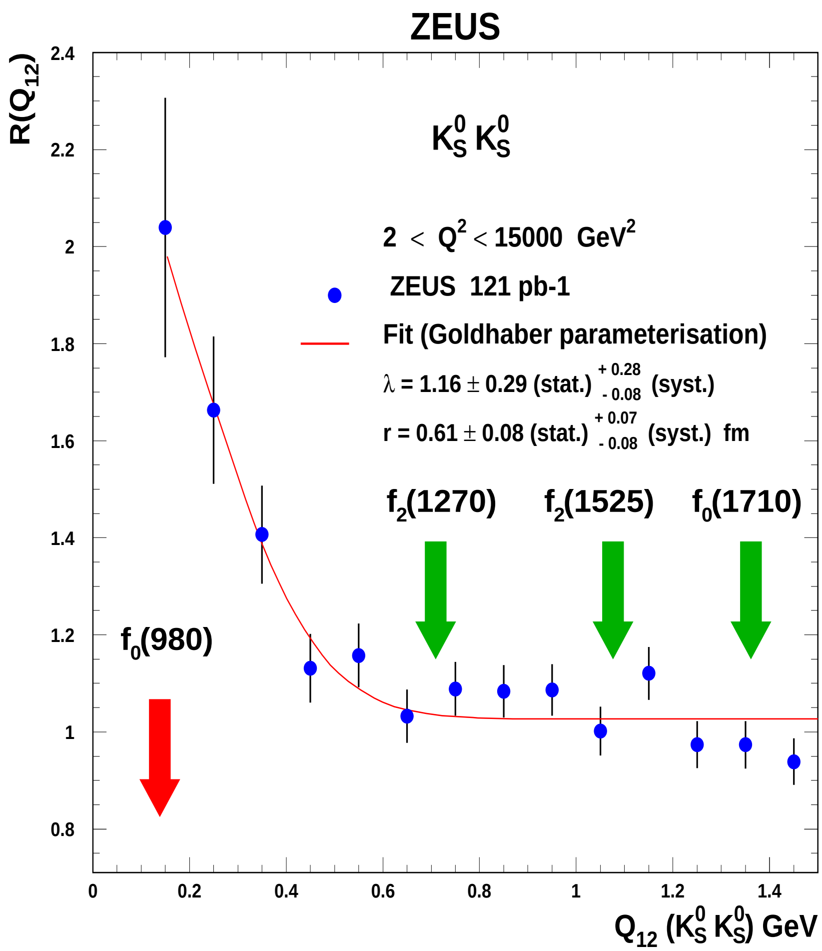


Figure 4: The two-particle correlation functions at $<Q^2>= 35\,\mathrm{GeV}^2$ for neutral kaons with fits to the Goldhaber function. Arrows indicate Q_{12} regions with contributions from resonances in the $K_s^0 K_s^0$ system.