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Bose-Einstein correlations of neutral and charged kaons in deep inelastic scattering at HERA

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Abstract

Bose-Einstein correlations between kaons (charged and neutral) have been observed for the first time in deep inelastic scattering with the ZEUS detector at HERA using an integrated luminosity of 121 pb^{-1}. The analysis was performed using the four-momentum difference of the kaon pair, $Q_{12} = \sqrt{-(p_1 - p_2)^2}$, where p_1, p_2 are the kaon four-momenta. The enhancement observed at small values of Q_{12} was parameterised using a Gaussian function which gives a measure of the fraction of pairs of identical particles that undergo interference, i.e. coherence, λ, and the radius of the production volume, r. The radii obtained for neutral and charged kaons are similar.

1 Introduction

The method of determination of the size and shape of the source from which particles originate has more than forty years history [1]. In this method Bose-Einstein correlations (BEC) of identical bosons with small momentum difference have been used. Measurements of the radius of the emission source have been performed for charged and neutral pions in essentially all types of particle interactions including heavy-ion collisions [2, 3]. For other bosons like kaons such information is scarce and comes mostly from BEC studies in hadronic collisions and e^+e^- annihilation at LEP energies [2].

This paper reports for the first time the results of BEC studies for charged $K^{\pm}K^{\pm}$ and neutral $K^0_SK^0_S$ kaon pairs in neutral current deep inelastic $e^{\pm}$p scattering (DIS) at HERA. The studies were performed in a wide range of the exchanged photon virtuality, Q^2. Previous results on BEC studies for charged pions in DIS [5, 6] indicated no sensitivity of the measured radius on the virtuality of the exchanged photon.

The measured radii for charged and neutral kaons are expected to be similar but the strength of the effect may be different since, unlike the charged kaons, the system of $K^0_SK^0_S$ can be formed from decays of mesons with the strangeness $\mathrm{S} = \pm 2$, as well as from mesons with $\mathrm{S} = 0$ [2, 4].

The DIS results for the radius of the particles source, r, and the strength of the effect, λ, are compared with those from e^+e^- annihilation events at LEP. Possible differences may be understood by the influence of the proton fragmentation process.

2 Data sample and particle selection

A DIS data sample of 121 pb^{-1} was taken from positrons/electrons colliding with protons during the period 1996 - 2000. The beam energies were 27.5 GeV and 820/920 GeV for positrons/electrons and protons respectively. The ZEUS detector is described in detail elsewhere [7]. DIS events were selected in the Q^2 range, $2 < \mathrm{Q}^2 < 15000$ GeV^2. Important components for the present analysis were the central tracking detector (CTD) and the calorimeter (CAL). Good quality tracks measured in the CTD and fitted to the primary vetex were selected requiring cuts on transverse momentum and polar angle (pseudorapidity): $\mathrm{p}_t > 0.15$ GeV and $\mid \eta \mid < 1.75$. In addition the tracks were required to pass through more than three CTD superlayers. The energy-loss measurement, dE/dx, was used for particle identification both in data and Monte Carlo. In Fig. 1 dE/dx against momentum is shown for tracks with positive charge. The band used for kaon selection is also shown in this figure. The maximum particle momentum was set to 0.9 GeV. Such a selection ensured 90 % purity of the kaon sample. However, the identification efficiency at

0.9 GeV is rather low. A similar identification procedure was applied to negative tracks with a slightly different selection band. K_S^0 mesons were identified in similar way as in a previous publication [8] by their charged decay mode, $K_S^0 \to \pi^+\pi^-$, using pairs of tracks originating from secondary vertices. Assigning the pion mass to the tracks, the invariant mass $M(\pi^+\pi^-)$ was calculated and a candidate was accepted if M was within $\pm$ 20 MeV around the nominal PDG K_S^0 mass. Using the following cuts on invariant masses: $M(p\pi)$ $>$ 1.121 GeV and $M(e^+e^-) > 0.08$ GeV, contributions from Λ ($\bar{\Lambda}$) decays and photon conversion events were removed.

3 Method of measurement

The two-particle correlation function $R(Q_{12})$ was calculated using the double ratio method according to the following expression:

$$R(Q_{12}) = \frac{P(Q_{12})^{\rm Data}}{P_{\rm mix}(Q_{12})^{\rm Data}} / \frac{P(Q_{12})^{\rm MC,noBEC}}{P_{\rm mix}(Q_{12})^{\rm MC,noBEC}} , \qquad (1)$$

where the reference sample $P_{\rm mix}$ contains pairs of bosons coming from different events (the so-called mixed-event sample), Q_{12} is four-momentum difference between two particles: $Q_{12}^2 = -(p_1 - p_2)^2 = M^2 - 4m_{boson}^2$ and M is the invariant mass of two identical bosons each with mass m_{boson}. In Eq. 1 $P(Q_{12})$ and $P_{\rm mix}(Q_{12})^{\rm Data}$ are the two-particle normalized density distributions for the data and the event-mixed sample respectively. For the Monte Carlo events, which were free of BEC, these densities are defined using a similar procedure. This method is applied to remove correlations other than BEC.

A Goldhaber-like expression, assuming a Gaussian shape of the particle source [9], was used to fit the data and to extract the values of r and λ:

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

where α is a normalisation factor and the $(1+\delta Q_{12})$ term describes the background coming from long-range particle correlations. The parameter λ, the strength of the correlation, reflects the degree of incoherence (0 for a completely coherent source, and 1 for complete incoherence) and r is the radius of the boson-emitting source.

4 Results

Figure 2 shows the correlation function of charged kaons obtained by the double ratio method in Eq. 1 together with the fit using the Goldhaber parametrization. The parameter δ was set to zero in the fitting procedure since linear behaviour of the background in the high Q_{12} region was found. The extracted BEC parameters for the radius r and the BE strength λ are:

$$\begin{aligned} r &= 0.57 \pm 0.09^{+0.15}_{-0.06} \text{ fm}, \\ \lambda &= 0.31 \pm 0.06^{+0.09}_{-0.06}. \end{aligned}$$

The main sources of the systematic uncertainties are the track quality selection, the fitting procedure and the construction of the reference sample. The radius value for charged kaons is consistent with that for charged pions in DIS [6] which was measured to be $r = 0.666 \pm 0.009^{+0.022}_{-0.036}$ fm. However, the λ value for kaons is smaller than the measured value for pions of $\lambda = 0.475 \pm 0.007^{+0.011}_{-0.003}$. Figure 3 shows the comparison of DIS and LEP results [10, 11] for the radius and λ. Most of the DIS data populate the proton fragmentation region (not present in e^+e^- annihilation events) where the production and decays of resonances may significantly increase the number of non prompt kaons in the final state. This will decrease the values of λ.

Similar to the case of charged kaons, Eq. 2 was used to fit the correlation function calculated for neutral kaon pairs. The results which are presented in figure 4 are:

$$\begin{aligned} r &= 0.61 \pm 0.08^{+0.07}_{-0.08} \text{ fm}, \\ \lambda &= 1.16 \pm 0.29^{+0.28}_{-0.08}. \end{aligned}$$

Their uncertainties arise from track quality selection, fitting procedure and the construction of the reference sample. The radius for neutral kaons is in good agreement with that for charged kaons but the value of the λ is significantly larger than that for charged kaons. The larger value of the correlation function of the neutral kaons may be explained by two contributions: one from true BEC and another from the decay of the threshold resonance $f^0(980)$ which is not well described in the Monte Carlo simulation. It was verified that if the contribution of this resonance was about 8 % of the total number of $K^0_S K^0_S$ pairs, then the contribution to the λ parameter can be as large as 30 %. The corresponding change in the value of r is small. Figure 5 shows a comparison of DIS results for neutral kaons with the results obtained in LEP experiments [10, 12, 13]. The radius value obtained in DIS agrees with the measurements from LEP. Although consistent within the uncertainties, the value of λ is larger in DIS than for that measured by ALEPH and DELPHI and more similar to the measurement from OPAL. This is consistent with an influence from the $f^0(980)$ which is not removed here and in the OPAL measurement but is by the ALEPH and DELPHI experiments.

5 Conclusions

Bose-Einstein correlations of neutral and charged kaons have been studied in deep inelastic scattering at HERA. The values of the radii for charged and neutral kaons agree within errors and with the values for pions. They also agree, within errors, with the measurements made in e^+e^- reactions at LEP for pions and kaons. The observed differences for the strength of the effect, λ, between DIS and e^+e^- results may be related to the influence of the proton fragmentation mechanism and a larger production of resonances. For neutral kaons some part of the enhancement observed in the correlation function comes from the contribution of the $f^0(980)$ resonance which can increase the λ value by more than 30%.

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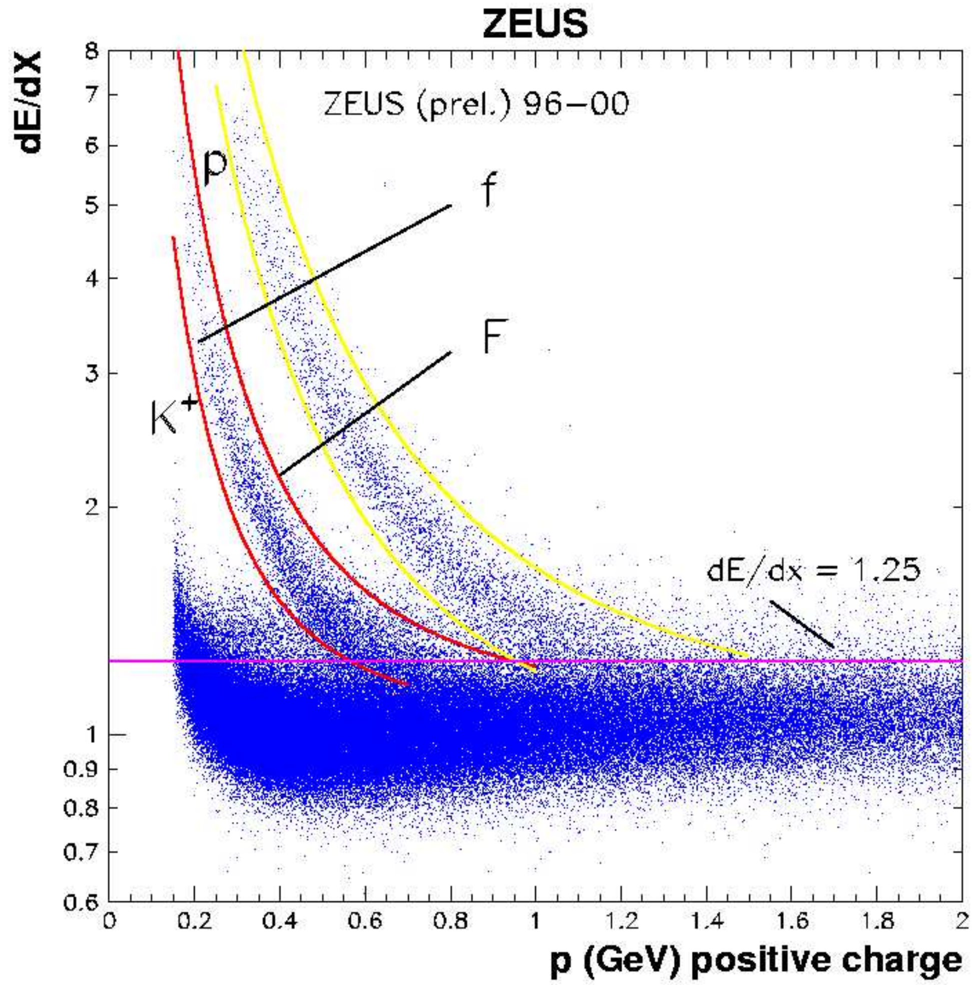

Figure 1: *An example (subsample with 400 k events) of the energy-loss dE/dx (normalised to a minimum ionising particle) as a function of the momentum p for tracks with positive charge. The tracks with* $f < dE/dx < F$*,* $dE/dx > 1.25$ *and* $p < 0.9$ *GeV were taken as* K^+*.*

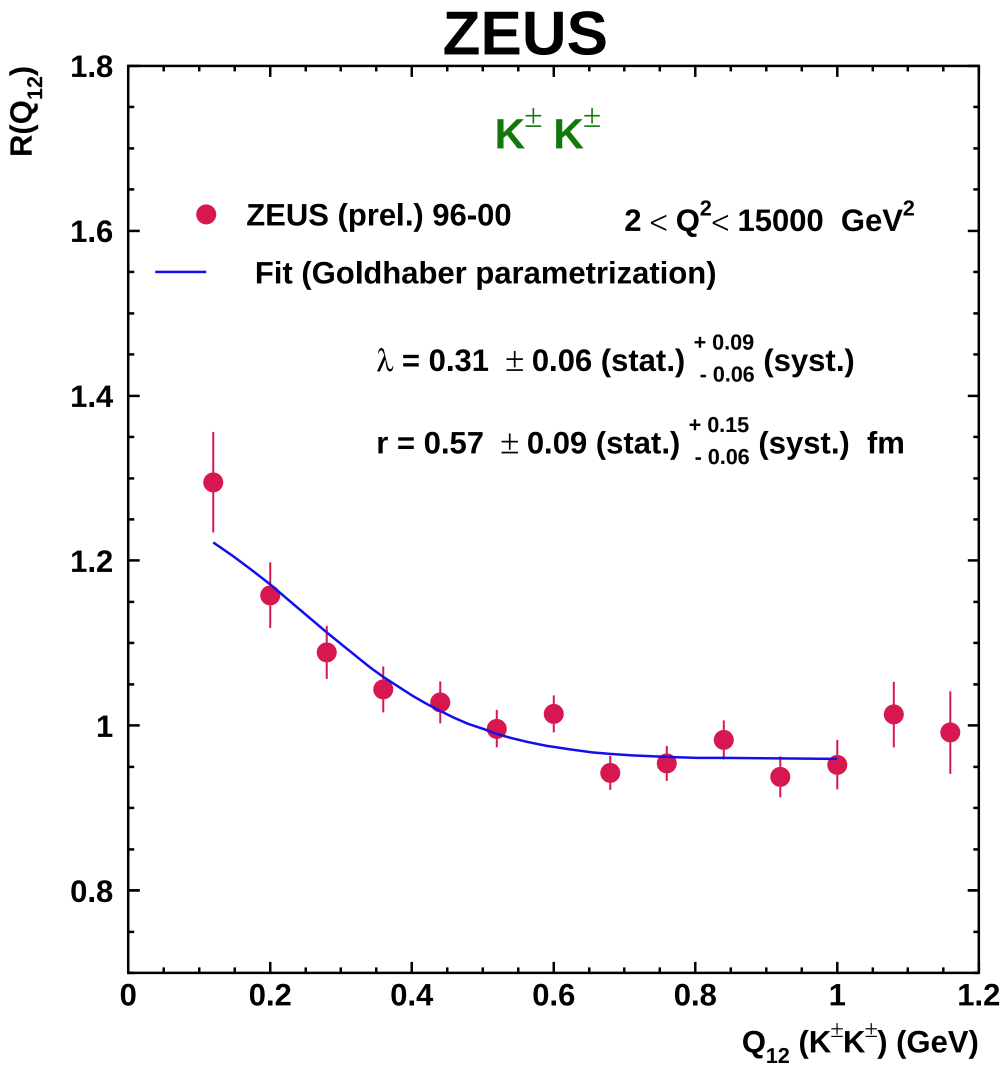

Figure 2: *The two particle correlation function $R(Q_{12})$ (1) for charged kaons with a fit to Eq. (2).*

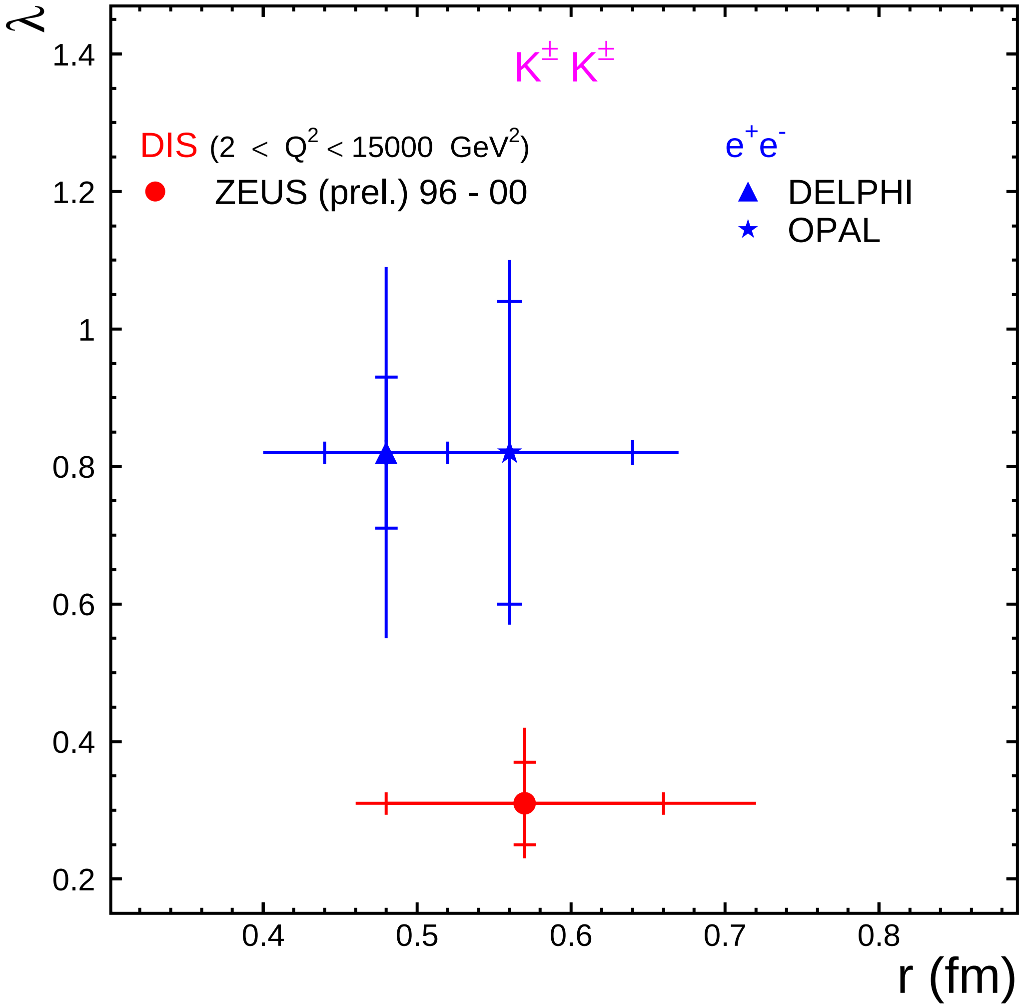

Figure 3: *Comparison of DIS and e^+e^- LEP results for r and λ obtained from Bose-Einstein correlation studies of charged kaons.*

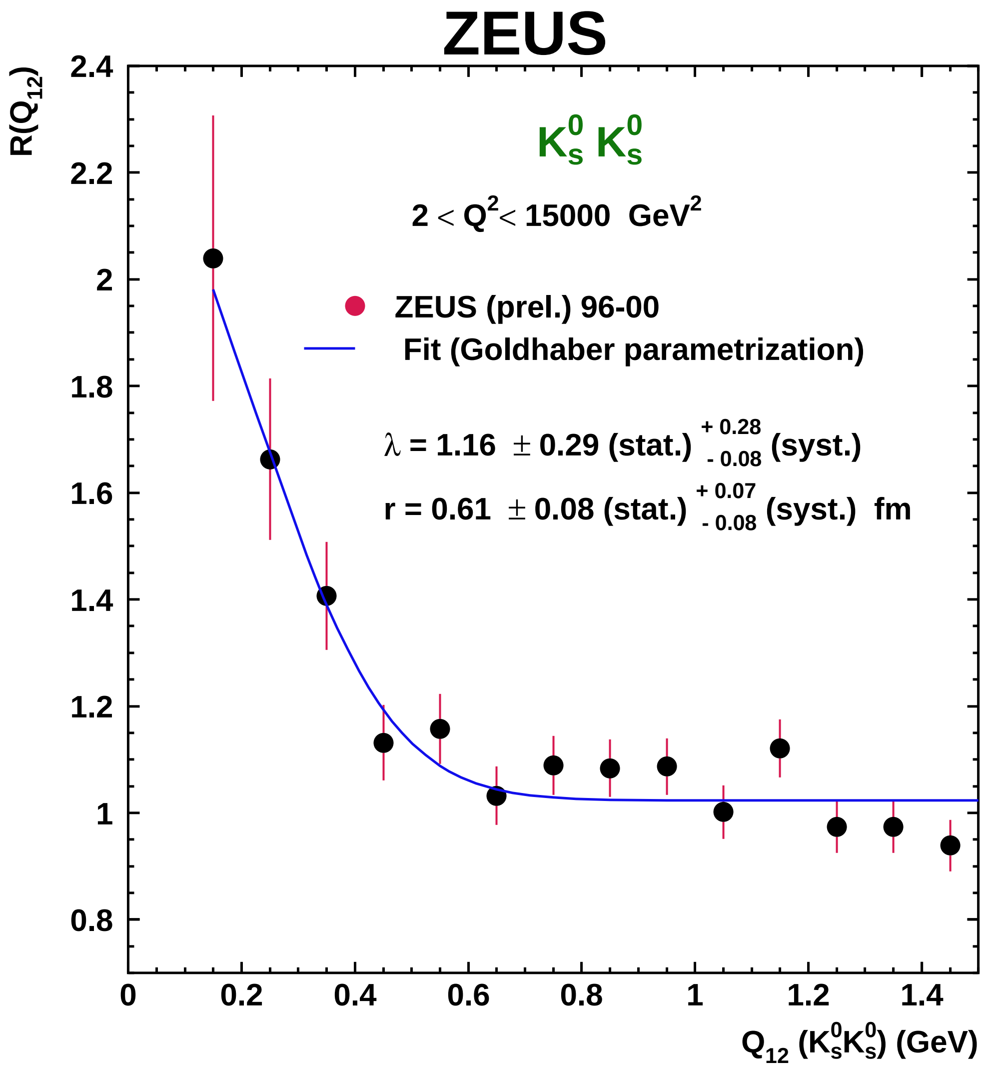

Figure 4: *The two particle correlation function $R(Q_{12})$ (1) for neutral kaons with a fit to Eq. (2).*

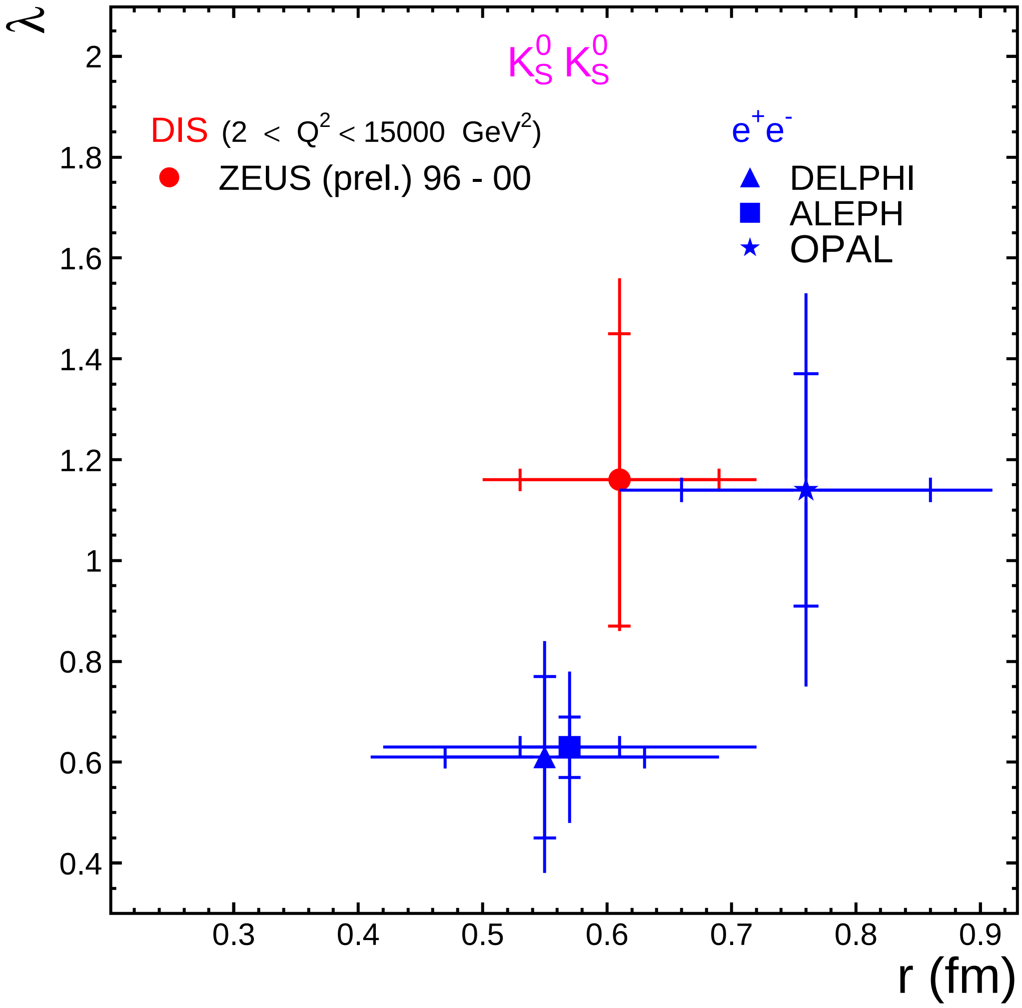

Figure 5: *Comparison of DIS and e^+e^- LEP results for r and λ obtained from Bose-Einstein correlation studies of neutral kaons.*