ONE- AND TWO-DIMENSIONAL BOSE-EINSTEIN CORRELATIONS IN DEEP INELASTIC SCATTERING AT HERA

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Measurements of Bose-Einstein correlations in one and two dimensions are presented for deep inelastic *ep* scattering measured with the ZEUS detector at HERA using an integrated luminosity of 82.6 pb^{-1}. The Bose-Einstein effect is independent of the virtuality of the exchanged photon, Q^2. The two-dimensional shape of the source was investigated in the longitudinally co-moving system. A significant difference between the transverse and the longitudinal dimensions of the source is observed.

1 Introduction

The shape of the BE correlations in relative momentum space is related to the spatial dimensions of the production source. Therefore studies of the BE effect may lead to a better understanding of the space-time structure of the source of the identical bosons. In deep inelastic scattering (DIS), the production volume depends on the virtuality of the exchanged photon, Q^2. If the BE correlations are sensitive to the size of the production volume, one should expect a reduction of the BE effect with increasing Q^2, since the transverse size of the virtual photon decreases with increasing Q^2. Alternatively, the BE effect can be explained in the framework of the Lund fragmentation model [1]. In this case, no sensitivity of this effect to the scale Q^2 is expected, since the BE correlations between two identical pions is a measure of the string tension.

This paper investigates the BE correlations in one- and two-dimensions in neutral current e^+p DIS, focusing on studies of a dependence of the BE interference on Q^2. Furthermore, the correlations were studied in the longitudinal and transverse directions in order to probe the shape of the pion source.

2 Definition of the measured quantities

Bose-Einstein correlations are parameterized using a Gaussian expression for the normalized two-particle density :

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

where $Q_{12} \equiv \sqrt{-(p_1-p_2)^2} = \sqrt{M^2-4m_{\mathrm{boson}}^2}$ is the Lorenz-invariant momentum difference between the two bosons, which is related to the invariant mass M of the two particles with four-momenta p_1 and p_2 and masses m_{boson}. All charged particles are regarded as pions. The parameter λ is a measure of the degree of coherence, while r is the radius of the production volume. The parameter β is used to take into account long-distance non-BE correlations.

To calculate $R(Q_{12})$, the inclusive two-particle density ρ was defined as $\rho = (1/N_{\mathrm{ev}})\mathrm{d}n_{\mathrm{pairs}}/\mathrm{d}Q_{12}$, where n_{pairs} is the number of particle pairs and N_{ev} is the number of events. The densities were calculated for like-charged particle combinations ($\rho(\pm,\pm)$) and for unlike-charged combinations ($\rho(+,-)$), and the ratio computed as $\xi = \rho(\pm,\pm)/\rho(+,-)$. This technique helps to remove correlations due to the topology and global properties of DIS events contributing to $\rho(\pm,\pm)$. In order to reduce still present non-BE effects, a Monte Carlo sample without the effect was used to calculate the $\xi^{\mathrm{MC,noBE}}$, and then non-Bose-Einstein effects were removed by use of the double ratio, $R(Q_{12}) = \xi^{\mathrm{data}}/\xi^{\mathrm{MC,noBE}}$, assuming that the BE effect is independent of other types of correlations.

The shape of the correlation function is studied in the transverse and longitudinal directions. using the longitudinally co-moving system (LCMS). For *ep* collisions, the LCMS can be defined for each pair of particles with momenta $\mathbf{p_1}$ and $\mathbf{p_2}$, as the system in which the sum of the two momenta, $\mathbf{p_1}+\mathbf{p_2}$, is perpendicular to the $\gamma^* q$ axis of the Breit frame. $\mathbf{Q} = (\mathbf{p_2}-\mathbf{p_1})$, can be decomposed in the LCMS into transverse, Q_T, and longitudinal, Q_L, components. The longitudinal direction is aligned with the direction of motion of the initial parton, therefore, in the string model, the LCMS is the local rest frame of a string. The BE effect can be parameterized using the two-dimensional function:

$$R(Q_T,Q_L) = \alpha\,(1+\beta_t\,Q_T+\beta_l\,Q_L)\,(1+\lambda\,e^{-r_T^2\,Q_T^2-r_L^2\,Q_L^2}), \tag{2}$$

where r_T and r_L reflect the transverse and longitudinal extent of the boson source.

3 Event samples

Two ZEUS ([2]) data samples were used for the present analysis. The data for medium and high-Q^2 events were taken during the 1998-2000 period, corresponding to an integrated luminosity of 82.6 ± 1.2 pb^{-1}. A positron or electron beam energy was 27.5 GeV and a proton beam energy was 920 GeV. The second sample was for low-Q^2 events taken with the BPC. This sample corresponds to 3.9 pb^{-1} of the data taking during 1997, when the proton energy was 820 GeV and the electron beam energy was 27.5 GeV.

The Monte Carlo (MC) events were generated with the ARIADNE 4.07 model [3].

4 Results

Figure 1 shows the measured $R(Q_{12})$ together with the Gaussian fit (Eq. (1))

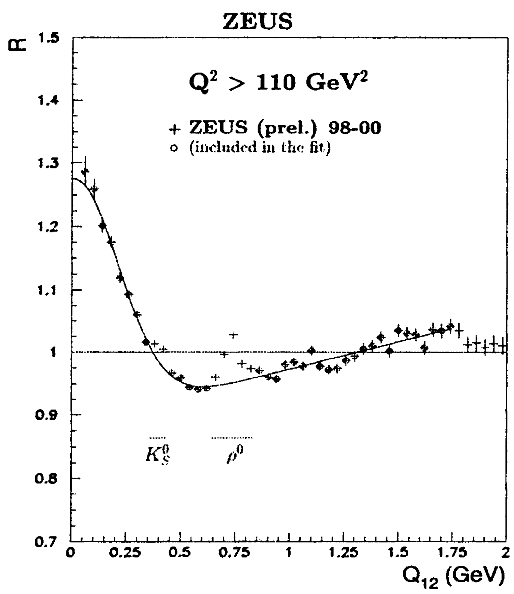

Figure 1: The measured Bose–Einstein correlation function $R(Q_{12})$, together with the Gaussian fit. The error bars show the statistical uncertainties. The data points included in the fit are shown as the circles

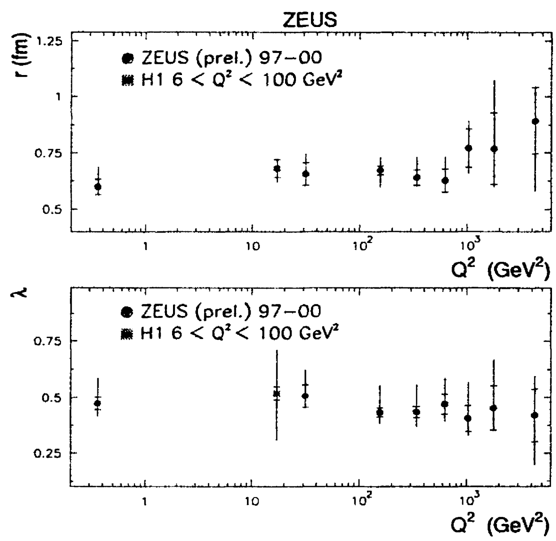

Figure 2: The extracted radius r, and the incoherence parameter, λ, from the Gaussian fit as function of Q^2

The regions affected by imperfections in the simulations of K_s^0 and ρ^0 decays were excluded from the fit.

The extracted parameters are :

$$\lambda = 0.434 \pm 0.008(\text{stat})^{+0.122}_{-0.053}(\text{syst.})$$
$$r = 0.671 \pm 0.012(\text{stat})^{+0.058}_{-0.045}(\text{syst.})\ \text{fm}$$

The BE parameters as functions of Q^2 are shown in Fig. 2.

Within errors, the data indicate no variation with the virtuality of the exchanged photon in the range from 0.1 to 8000 GeV^2. This conclusion is also consistent with the H1 data [4]

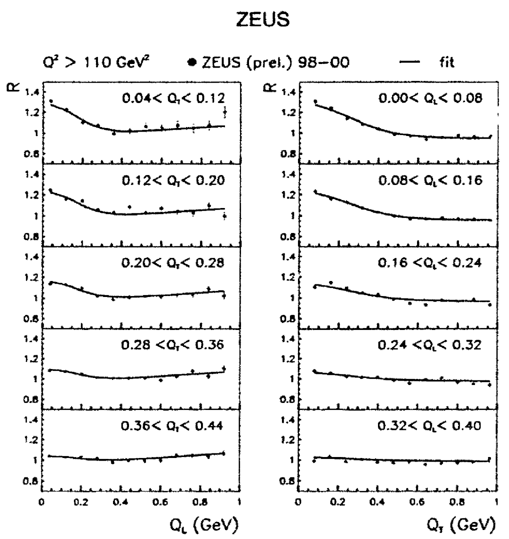

Figure 3: The projections of the two–dimensional BE function $R(Q_T, Q_L)$ calculated ad $Q^2 > 110\text{GeV}^2$

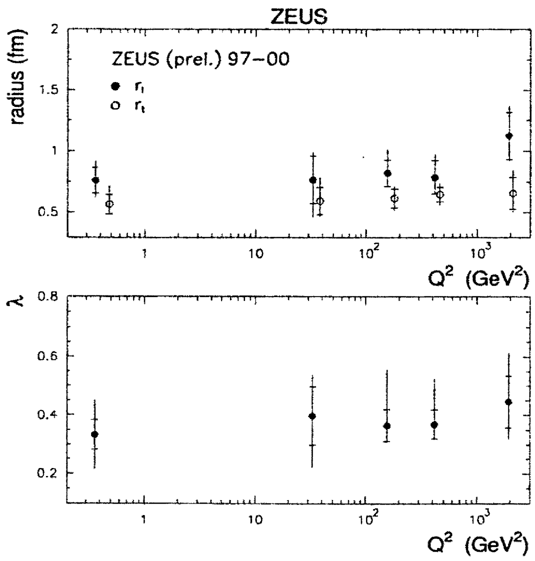

Figure 4: The extracted radii, r_t and r_l, and the incoherence parameter, λ, as function of Q^2 for the two–dimensional correlation function $R(Q_T, Q_L)$

The BE effect in the transverse and the longitudinal dimensions for the sample $Q^2 > 110\,\text{GeV}^2$ can be described by the parameters:

$\lambda = 0.35 \pm 0.04(\text{stat})^{+0.12}_{-0.03}(\text{syst.})$

$r_l = 0.87 \pm 0.06(\text{stat})^{+0.07}_{-0.05}(\text{syst.})\ \text{fm}$

$r_t = 0.58 \pm 0.05(\text{stat})^{+0.07}_{-0.02}(\text{syst.})\ \text{fm}$

$r_t/r_l = 0.67 \pm 0.08(\text{stat})^{+0.05}_{-0.01}(\text{syst.})$

The BE correlations in transverse and longitudinal slices are shown in Fig. 3 together with the fit to Eq. (2). Figure 4 shows the extracted BE parameters as a function of Q^2 for the two-dimensional measurements. No Q^2 dependence of the BE strength is observed, furthermore, the size of the elongation given by r_T/r_L shows no variations with Q^2.

5 Conclusions

One- and two-dimensional Bose-Einstein correlations have been studied in deep inelastic scattering with the ZEUS detector at HERA. The effect was measured as a function of the photon virtuality, Q^2, in the range from 0.1 to 8000 GeV^2. Transverse and longitudinal Bose-Einstein correlations have been measured for the first time in DIS. The results indicate that the emitting source of identical pions, as observed in the LCMS, has an elongated shape. The BE effect in one and two dimensions is observed not to depend on the virtuality of the exchanged photon. The elongation of the pion source is also independent of Q^2. The observed Bose-Einstein correlations are consistent with most e^+e^- measurements, and are not in conflict with hadron-hadron. All of this implies that the BE interference is insensitive to details of the hard scattering process

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