BOSE–EINSTEIN CORRELATIONS IN DIS AT HERA*

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Bose–Einstein correlations of identical charged pions are studied in deep inelastic *ep* scattering events measured with the ZEUS detector at HERA. In one-dimensional analysis the radius of the particle production source and the correlation strength are independent of the exchanged photon virtuality Q^2 in the range between 0.1 and 8000 GeV^2. No significant difference was found between the correlations measured in the target and current region of the Breit frame for $Q^2 > 100$ GeV^2. The result indicates insensitivity of the radius of the source to the underlying hard process. Two-dimensional analysis performed in the Longitudinally CoMoving System indicates an elongated shape of the source.

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1. Introduction

The Bose–Einstein correlations (BEC) between pairs of identical bosons in multi-hadron final states have been extensively studied in lepton–lepton, lepton–hadron, hadron–hadron and heavy ion interactions [1–3]. The BEC measurements in the relative momentum space help to reconstruct the space-time picture of particle emission.

In this paper we focus on studies of the BEC dependence on the $Q^2 = -(k-k^{'})^2$ (k and $k^{'}$ denote the four-momenta of the initial and final lepton respectively). In deep inelastic scattering (DIS) the production volume may depend on the Q^2 since the transverse size of the virtual photon decreases with increasing Q^2. If the BEC is sensitive to hard subprocesses then the effect would depend on Q^2. An additional information may come from measurements of the BEC effect in the current and target regions of the Breit frame which are known to have rather different properties [4].

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On the other hand, the size of region where BEC exist may be determined by the fragmentation (soft) process. In the Lund string model [5,6], no Q^2 dependence is expected and BEC can measure the tension of the colour string between partons. The two-dimensional analysis of the BEC in DIS appears sensitive to a possible elongation of the source which is expected in the Lund string model [6].

2. Results

The analysis used 121 pb^{-1} of data taken during 1996–2000 period with positron/electron beam energy of 27.6 GeV and a proton beam energy of 820 GeV (1996-1997) or 920 GeV (1998-2000). Besides the high Q^2 sample ($4 < Q^2 < 8000$ GeV^2) also low-Q^2 events ($0.1 < Q^2 < 1.0$ GeV^2) were included in analysis.

2.1. One-dimensional study

The BEC can be expressed by the two-particle correlation function $R^{\mathrm{data}}(Q_{12}) = \rho(Q_{12})/\rho_0(Q_{12})$ where $Q_{12} = \sqrt{-(p_1 - p_2)^2}$ is the Lorentz-invariant four-momentum transfer (p_1, p_2 are the four-momenta of the particles which are assumed to be pions). The density $\rho(Q_{12})$ is calculated for like-charged particle combinations $(\pm,\pm)$ and $\rho_0(Q_{12})$ — for unlike-charged combinations $(+,-)$ serving as a reference. Such ratio helps to remove correlations due to topology and global properties of DIS events. The corrections for short-range correlations (resonances decays contributing to densities for $+,-$ combinations) and detector effects require use of the Monte Carlo sample without the BEC to create the $R^{\mathrm{MC,noBEC}}(Q_{12})$. Finally, the correlation function represented by the double ratio $R(Q_{12}) = R^{\mathrm{data}}/R^{\mathrm{MC,noBEC}}$ was fitted with the following expression [7]:

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

The parameter λ reflects the degree of incoherence of the source, while r corresponds to the size of the production volume. The parameter β takes into account a long-distance non-BEC contribution and α is a normalisation constant. In other approach, when the BEC are interpreted in the framework of the Lund model, the correlation strength, λ, is related to the string tension. In this case the correlation should have an approximately exponential shape [5,6] and the $\lambda \mathrm{e}^{-r^2 Q_{12}^2}$ term in Eq. (1) should be replaced by $\lambda' \mathrm{e}^{-r' Q_{12}}$. Both parametrisations were used in this analysis. The Q^2 dependence of the radius, r, and the incoherence parameter, λ, extracted from the fit (Eq. 1) are shown in Fig. 1 (left). For example, their values obtained for the high Q^2 sample were: $r = 0.666 \pm 0.009$ (stat.)$^{+0.022}_{-0.036}$ (syst.) fm and

$\lambda = 0.475 \pm 0.007$ (stat.)$^{+0.011}_{-0.003}$ (syst.). Within the statistical and systematic uncertainties, no Q^2 dependence is found for r and λ in the range of $0.1 < Q^2 < 8000$ GeV^2. The H1 DIS results [3], obtained in the Q^2 range $6 < Q^2 < 100$ GeV^2 are consistent with ZEUS data. Figure 1 (right) shows also the comparison of the BEC effect between the target and the current regions of the Breit frame. The $Q^2 > 100$ GeV^2 cut for current region allows for reliable measurement. No significant difference between the target and the current regions was found. The similar conclusions come from the analysis using the exponential parametrisation for $R(Q_{12})$. [1]

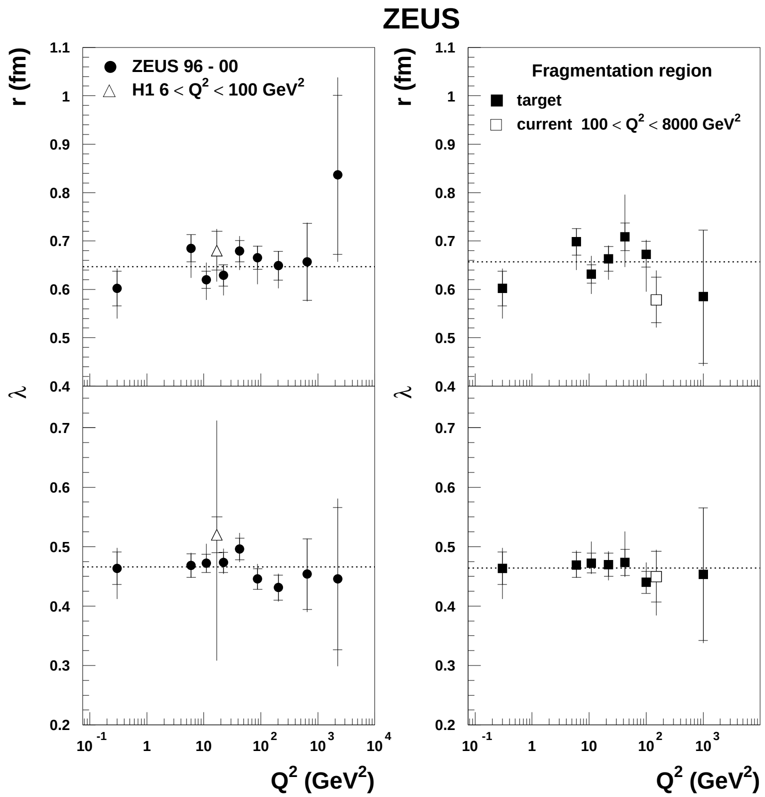

Fig. 1. The radius r and the incoherence parameter λ as a function of Q^2. (Left): The total phase space; (Right): The target and current regions of the Breit frame. The dotted lines show the average values.

[1] The Bose–Einstein correlation function was corrected in the data using the Gamow factors [8] to take into account Coulomb interactions between charged particles. It was found that Coulomb effect slightly increases the size of the radius r which was within the statistical and systematic errors of the measurement and thus does not change the conclusions.

2.2. Two-dimensional study

The pion source shape was estimated by studying the BEC in two dimensions. For this purpose the Longitudinally CoMoving System (LCMS) [9] was used. For DIS, the LCMS was defined for each pair of particles with three-momenta $\boldsymbol{p}_1$ and $\boldsymbol{p}_2$, where $\boldsymbol{p}_1 + \boldsymbol{p}_2$, was perpendicular to the axis $\gamma^* q$ (Fig. 2, left). The difference $\boldsymbol{Q} = (\boldsymbol{p}_2 - \boldsymbol{p}_1)$, was decomposed in the LCMS into the transverse, $Q_{\rm T}$, and longitudinal, $Q_{\rm L}$, components. The longitudinal direction is aligned with the direction of the initial quark motion. In the Lund string model the LCMS is the local rest frame of a string. In the BEC studies in LCMS the following, two-dimensional parametrisation was used:

$$R(Q_{\rm T}, Q_{\rm L}) = \alpha(1 + \beta_t Q_{\rm T} + \beta_l Q_{\rm L})(1 + \lambda {\rm e}^{-r_{\rm T}^2 Q_{\rm T}^2 - r_{\rm L}^2 Q_{\rm L}^2}) , \qquad (2)$$

where $r_{\rm T}$ and $r_{\rm L}$ are the transverse and longitudinal size of the pion source. In Fig. 2 (right) the values of the parameters $r_{\rm L}$, $r_{\rm T}$ and λ extracted from the fit are shown. The result indicates the elongated shape of the pion source: $r_{\rm L}$ is significantly larger than $r_{\rm T}$. For high Q^2 data sample the ratio $r_{\rm T}/r_{\rm L}$ $= 0.72 \pm 0.03$ (stat.)$^{+0.04}_{-0.03}$ (syst.) was obtained. No Q^2 dependence of the BE radii was found.

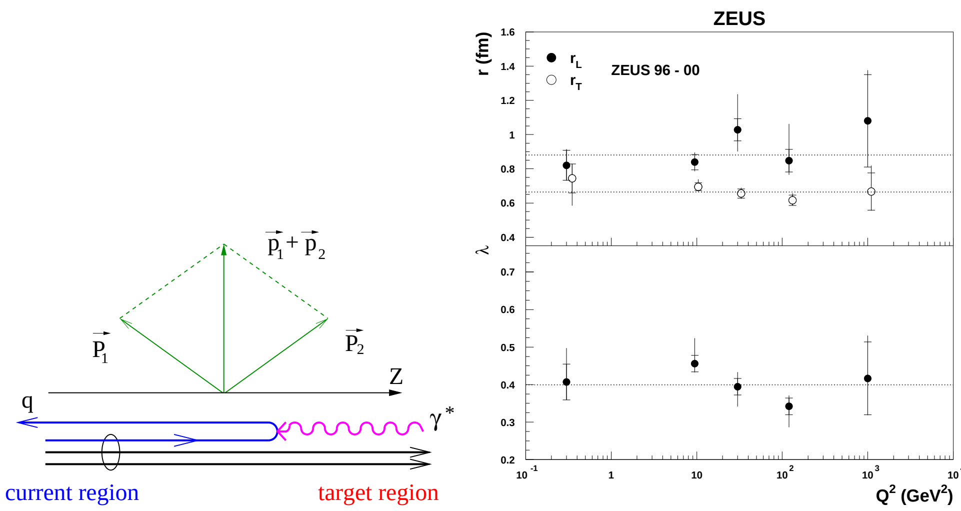

Fig. 2. (Left): Definition of the LCMS for a pair of particles used in DIS study; (Right): The radii $r_{\rm L}$, $r_{\rm T}$ and incoherence parameter λ as function of Q^2 obtained from the fit to $R(Q_{\rm T}, Q_{\rm L})$.

2.3. Comparison with other experiments

The results can be compared with experiments [10–15] which use also the unlike-charged combinations as reference sample. Our result agrees well with the result of EMC [10] (μp data at $Q^2 > 4$ GeV^2) and H1 data [3]. There is also agreement with the LEP1 average, r=0.78 ± 0.01 (stat.) ± 0.16 (syst.) [16] and LEP2 results [12]. The radii obtained for hadron–hadron interactions [13, 14] seem to be larger than those for DIS. Since the BEC results depend significantly on the details of the experimental procedure, it is difficult to say if observed differences reflect the different nature of studied processes.

The results on the pion source elongation are consistent with the ones obtained at LEP [15].

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