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# BOSE–EINSTEIN CORRELATIONS IN DIS*

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Measurements of Bose–Einstein correlations (BEC) are presented for deep inelastic *ep* scattering using the ZEUS detector at HERA using an integrated luminosity of 83 $\text{pb}^{-1}$. The two-particle correlation functions were studied as a function of the virtuality of the exchanged photon, $Q^2$, assuming a Gaussian shape of the BEC source. The results do not show a dependence of the BEC effect in the range from 25 to 5000 $\text{GeV}^2$.

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## 1. Introduction

For a pair of identical bosons, the quantum mechanical wave-function has to be symmetric under particle exchange. As a consequence, interference effects are expected between identical bosons which are emitted close to each other in phase space. This alters the two-particle density at small phase-space separations and leads to Bose–Einstein correlations (BEC), which were first observed by Goldhaber *et al.* [1] for like-charged hadrons in $p\bar{p}$ collisions.

The shape of the BEC correlations in relative momentum space is related to the spatial dimensions of the production source. Therefore, the experimental study of BEC should eventually lead to better understanding of the space-time structure of the source of identical bosons.

The BEC were investigated in neutral current $e^+p$ deep inelastic scattering (DIS), focusing on studies of a dependence of the BEC on the virtuality of the exchanged photon, $Q^2 = -q^2 = -(k - k^{'})^2$ ($k$ and $k^{'}$ denote the four-momenta of the initial- and final-state positrons, respectively). If the BEC reflect the size of the production volume, one should see the reduction

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of the BEC effect with increasing $Q^2$, since the transverse size of the virtual photon decreases with increasing $Q^2$. However, the BEC measured by the H1 Collaboration [2] did not indicate a $Q^2$ dependence in the range of $6 < Q^2 < 100$ GeV$^2$.

In this paper, the BEC are measured with a much higher precision than before in *ep* collisions. The luminosity used in this study allows to extend the kinematic range in $Q^2$ to much larger values than before [2], $Q^2 \simeq 5000$ GeV$^2$.

## 2. Experimental setup and data sample

During the 1998–2000 period, $83.0 \pm 1.2$ pb$^{-1}$ of data were taken with a positron/electron beam energy of 27.5 GeV and a proton beam energy of 920 GeV.

ZEUS is a multipurpose detector described in detail elsewhere [3]. Of particular importance in the present study are the Central Tracking Detector (CTD) and the CALorimeter (CAL).

The DIS event kinematics can be determined by $Q^2$ and the Bjorken variable $x = Q^2/(2P \cdot q)$, where $P$ is the four-momentum of the proton. The variable, $y$, is related to these two variables by $y \simeq Q^2/sx$, where $\sqrt{s}$ is the positron–proton center-of-mass energy. The analysis is based on the CTD tracks assigned to the primary event vertex, without particle identification.

## 3. Definition of the measured quantities

The BEC can be parameterized using the Goldhaber expression for the normalized two-particle density [4]:

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

where $Q_{12} \equiv \sqrt{-(p_1 - p_2)^2} = \sqrt{M^2 - 4m^2_{\mathrm{boson}}}$ 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 mass $m_{\mathrm{boson}}$. The parameter $\lambda$ reflects the degree of incoherence, while $r$ corresponds to the size of the production volume. The parameter $\beta$ takes into account a long-distance non-BEC contribution.

To calculate $R$, the two-particle inclusive density $\rho$ was defined as $\rho = (1/N_{\mathrm{ev}})dn_{\mathrm{pairs}}/dQ_{12}$, where $n_{\mathrm{pairs}}$ is the number of particle pairs and $N_{\mathrm{ev}}$ is the number of events. The densities were calculated for like-charged particle combinations $(\rho(\pm,\pm))$ and for unlike-charged combinations $(\rho(+,-))$, and then the ratio was computed: $\xi = \rho(\pm,\pm)/\rho(+,-)$. This ratio helps to remove correlations due to topology and global properties of DIS events. The quantity $\xi$ contains additional short-range correlations, mainly due to resonance decays (contributing to $\rho(+,-)$), which should further be removed. In order to extract the BEC, a Monte Carlo sample without the Bose–Einstein effect was used to calculate the $\xi^{\mathrm{MC,noBEC}}$, and then non-BEC correlations were removed in the double ratio, $R = \xi^{\mathrm{data}}/\xi^{\mathrm{MC,noBEC}}$.

Charged identical particles are subject to the Coulomb repulsion, which is not simulated by MC models. As a check, the BEC correlation function was corrected in the data using the Gamow factor [5]. It was found that after taking into account the Coulomb effect, the size of the BEC radius slightly increases, but it is still within the statistical and systematical errors of the present measurement and thus does not change the conclusions.

## 4. Results

Figure 1 shows the measured two-particle density together with the fit (1). The regions affected by imperfections in the simulation of $K_0^s$ and $\rho^0$ decays were excluded from the fit. The extracted values of the BEC effect

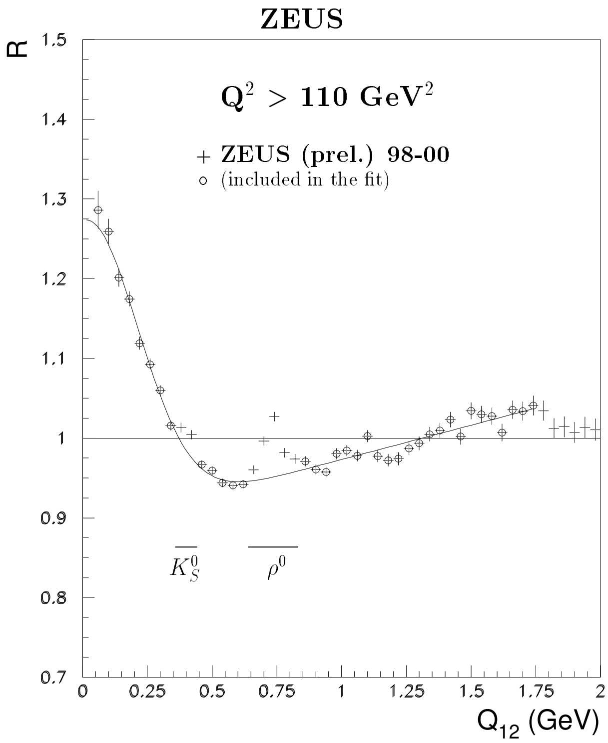


Fig. 1. The Bose–Einstein correlation function with the fit function (1). The error bars show the statistical uncertainties.

for $Q^2 > 110$ GeV$^2$ are

$$r = 0.671 \pm 0.016(\text{stat.})^{+0.030}_{-0.032}\,(\text{syst.})\ \text{fm},$$
$$\lambda = 0.431 \pm 0.012(\text{stat.})^{+0.042}_{-0.130}\,(\text{syst.}).$$

These two values agree with the H1 measurement for $6 < Q^2 < 100$ GeV$^2$ [2]: $r = 0.68 \pm 0.04^{+0.02}_{-0.05}$ fm and $\lambda = 0.52 \pm 0.03^{+0.19}_{-0.21}$.

Figure 2 shows that the DIS data are consistent with the LEP1-LEP2 measurements [6–9]. The comparison is also made with the H1 preliminary results for photoproduction data [10]. The latter suggests that events with a quasi-real photon have a larger interaction radius.

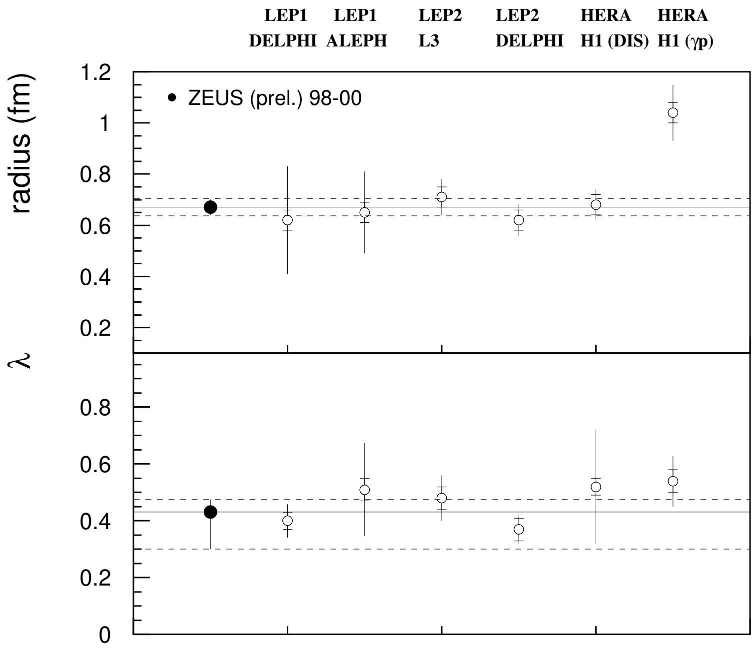


Fig. 2. Comparison of the measured BEC effect with other experiments.

The BEC effect was also investigated as a function of $Q^2$. The data do not indicate any $Q^2$ dependence in the range from 25 to 5000 GeV$^2$, as shown in Fig. 3.

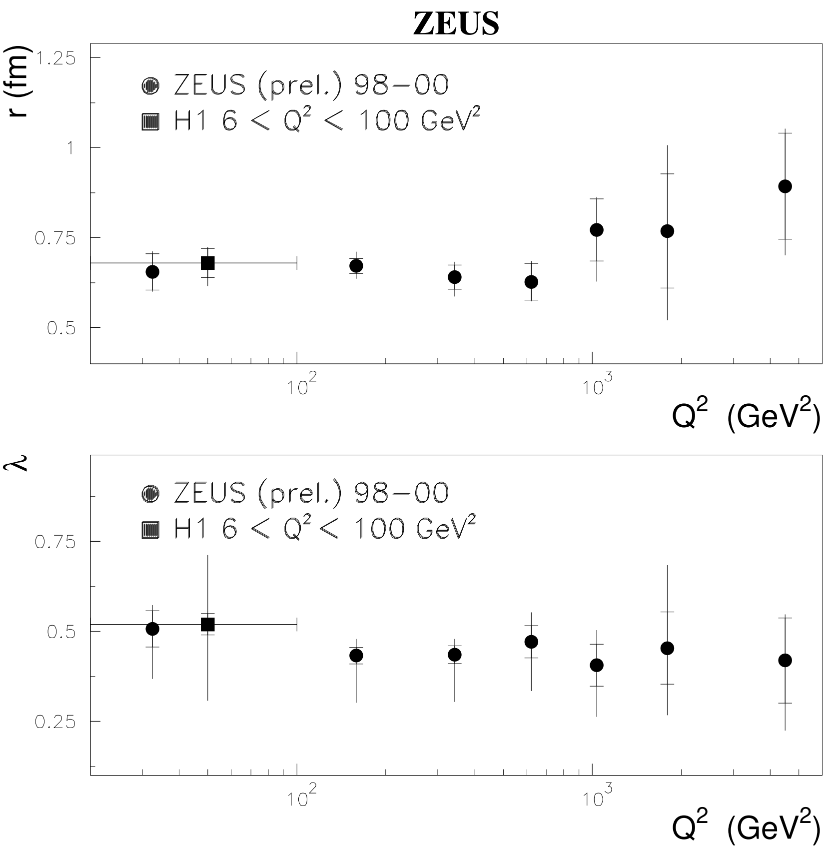


Fig. 3. The radius and the incoherence parameter $\lambda$ as a function of $Q^2$.

## 5. Conclusions

The 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 25 to 5000 GeV$^2$. The results do not show a dependence of the BEC effect on $Q^2$.

The observed Bose–Einstein correlations in DIS are consistent with the $e^+e^-$ measurements, suggesting that the effect is a universal hadronic final state phenomenon which is insensitive to details of the hard scattering process.

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