Bose-Einstein Correlations in Deep Inelastic e^+p Scattering at HERA

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INTRODUCTION

Bose-Einstein correlations (BEC) are a consequence of the fact that identical bosons obey Bose-Einstein statistics. The quantum mechanical interference arising from the particle-exchange symmetry of the wave function of identical bosons is observed as the tendency of identical bosons to group in phase space.

In 1953, the radio-astronomers Hanbury-Brown and Twiss [1] first applied this interference effect to determine the angular diameter of stellar objects.

In particle physics, the effect was first observed in 1959 by G. and S. Goldhaber, Lee and Pais [2], who noticed the tendency of like-sign π-pairs to have smaller opening angles than unlike-sign π-pairs.

Since 1959, BEC studies have been performed for different interactions in a wide range of CMS energies. Several parameterizations have been used. The goal is the extraction of information about the boson-emitting source [3].

THEORY

The two-particle correlation function is defined as

$$R = \frac{\rho_2(1,2)}{\rho(1)\rho(2)} \quad , \tag{1}$$

where $\rho_2(1,2)$ is the two-particle density distribution and $\rho(i)$ the single-particle density distributions.

Traditional calculations, following the geometrical interpretation used in radio-astronomy [1], yield

$$R(T) = 1 + \lambda \left|\tilde{\rho}(T)\right|^2 \quad , \tag{2}$$

where T is the four-momentum difference of the two particles; $\tilde{\rho}(T)$ the normalized Fourier transform of the source intensity distribution and λ the incoherence parameter ($\lambda = 1$ for a fully incoherent source).

If the pion source is a sphere of emitters with Gaussian density then

$$R(T) = R_0 \left(1 + \lambda \exp\left(-r^2 T^2\right)\right) \quad , \tag{3}$$

with R_0 an overall normalization factor and r the radius of the sphere. This parameterization is called the Goldhaber or Gaussian parameterization.

The traditional calculation assumes the absence of correlations between space-time (x) and momentum-energy (p). However, in HEP, the pion emitters move relativistically with respect to each other, thereby introducing x-p correlations. The x-p correlations are an inherent and basic property of the color-string fragmentation model of Andersson et al. [4]. This model predicts $R(T)$ to be roughly exponential:

$$R(T) = R_0(1 + \lambda \exp(-rT)) \quad . \tag{4}$$

In the expression (4) r is related to the string tension and is independent of the total interaction energy.

An alternative view comes from the connection with intermittency [5], i.e. the observation of large fluctuations in particle densities. These fluctuations reflect in the increase of multiparticle correlation functions with decreasing phase-space bins. It was noticed that this increase is the strongest for a like-charge sample, indicating the influence of BEC. Białas [6] argued that if the size of the particle source fluctuates on an event-by-event basis and/or if the source is a self-similar (fractal-like) object, the correlation function is expected to exhibit a power-law behavior in the invariant mass M of the pair

$$R(M) = A + B \left(\frac{1}{M^2}\right)^{\beta} \quad . \tag{5}$$

EXPERIMENTAL INFORMATION

The data used for this analysis [7] were taken in 1994, with the H1 detector [8] at HERA, where 27.5 GeV positrons collide with 820 GeV protons. The selected DIS sample is contained in the kinematic regions $6 \leq Q^2 \leq 100$ GeV^2 and $10^{-4} \leq x_{bj} \leq 10^{-2}$. It consists of 2500 diffractive and 48000 non-diffractive events, corresponding to an integrated luminosity of 1.26 pb^{-1}. Diffractive events are selected by requiring a large pseudo-rapidity gap around the proton-remnant direction. All charged particles are assumed to be pions.

Experimentally, (1) is determined via

$$R(T) = \frac{\rho_2^l(T)}{\rho_2^{ref}(T)} \quad , \tag{6}$$

where $\rho_2^l(T)$ is the two-particle distribution for a like-sign sample and $\rho_2^{ref}(T)$ is a reference distribution, ideally containing the same correlations as $\rho_2^l(T)$, except for the BEC. Commonly used reference distributions are: the event-mixed ρ_2^m, for which tracks from different events are combined, the unlike-sign ρ_2^u, where tracks of opposite charge are combined.

Monte Carlo studies have shown that neither ρ_2^m nor ρ_2^u are perfect reference distributions. The unlike-sign distribution is contaminated with dynamical correlations of K_S^0 and resonance decays, while the event-mixed distribution is biased by topological, momentum and charge conservation constraints. One can correct for these imperfections by using a Monte Carlo model without BEC and determining the double ratio

$$RR(T) = \frac{R^{data}(T)}{R^{MC}(T)} \quad . \tag{7}$$

In the following, LEPTO + ARIADNE is used to determine the MC distributions. Only results obtained with $\rho_2^m(T)$ will be shown, since they have smaller systematic errors and are not contaminated by resonance decays.

In fits to the data, parameterizations (3) and (4) have to be modified into

$$RR(T) = R_0\,(1 + aT)\left(1 + \lambda \exp\left(-r^2T^2\right)\right) \qquad \text{and} \tag{8}$$

$$RR(T) = R_0\,(1 + aT)\,(1 + \lambda \exp\left(-rT\right)) \quad , \tag{9}$$

respectively, where a allows for long-range correlations. The power-law parameterization (5) is used as is, in a restricted T interval.

EXPERIMENTAL RESULTS

The double ratio $RR(T)$ for non-diffractive events is shown in Fig. 1, with fits according to Eqs. (8), (9) and (5) superimposed. The fit parameters are collected in Tab. 1. The three fits differ mostly in the low T region, where the power law and the exponential describe the data better than the Gaussian. The modern models are clearly valid alternatives to the Gaussian fit.

TABLE 1. Results of the Gaussian, the exponential and the power-law fit.

	Gaussian	Exponential		Power law
a[GeV^{-1}]	0.02 ± 0.01	0.08 ± 0.04	β	$1.20 \pm 0.15\ ^{+0.15}_{-0.13}$
r[fm]	$0.54 \pm 0.03\ ^{+0.03}_{-0.02}$	$0.68 \pm 0.11\ ^{+0.09}_{-0.06}$	B [GeV$^{-2\beta}$]	$0.018 \pm 0.006\ ^{+0.007}_{-0.006}$
λ	$0.32 \pm 0.02\ ^{+0.06}_{-0.06}$	$0.64 \pm 0.06\ ^{+0.17}_{-0.16}$	A	$0.93 \pm 0.01\ ^{+0.00}_{-0.01}$
χ^2/ndf	96/72	85/72		49/49

The Gaussian parameterization is also used to fit the double ratio for the diffractive sample. On finds $r = 0.49 \pm 0.06^{\pm 0.02}_{\pm 0.03}$ fm and is, within statistical errors, the same as for the non-diffractive sample.

The Gaussian radius has been studied as a function of x_{bj}, Q^2 and W. The parameter value for three different regions in each variable can be found in

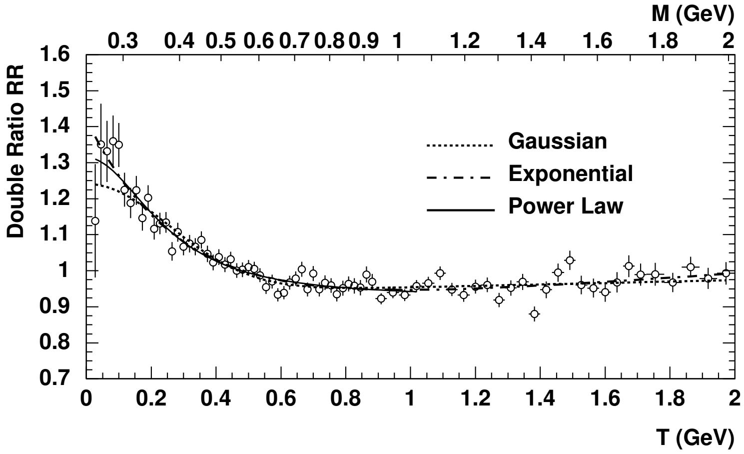

FIGURE 1. $RR(T)$ for non-diffractive events

Tab. 2. Within statistical errors, there is no evidence for a dependence on any of the variables x_{bj}, Q^2 or W.

TABLE 2. The Gaussian radius in different kinematic regions

r (fm)	0.60 ± 0.06	0.56 ± 0.05	0.44 ± 0.06
x	$0.0001 - 0.0006$	$0.0006 - 0.0019$	$0.0019 - 0.01$
r (fm)	0.52 ± 0.04	0.63 ± 0.08	0.47 ± 0.04
Q^2 (GeV^2)	$6 - 12$	$12 - 25$	$25 - 100$
r (fm)	0.52 ± 0.07	0.48 ± 0.03	0.68 ± 0.08
W (GeV)	$65 - 120$	$120 - 180$	$180 - 240$

In Tab. 3 the Gaussian radius is given for three intervals in observed charged multiplicity n. For each interval, the corresponding corrected mean charged multiplicity and the spread are given. The radius tends to increase with n. However, after including systematic errors, the slope is consistent with zero:

$$\frac{1}{\langle r \rangle}\frac{\mathrm{d}r}{\mathrm{d}n} = 0.085 \pm 0.026 \; {}^{+0.057}_{-0.048} \quad .$$

TABLE 3. The Gaussian radius as function of observed charged multiplicity n.

n	n_{corr}^{mean}	$\sigma_{n_{corr}^{mean}}$	r (fm)
$4 \leq n < 7$	4.9	1.1	0.42 ± 0.05
$7 \leq n < 12$	8.2	1.6	0.58 ± 0.05
$n \geq 12$	13.6	2.4	0.81 ± 0.12

In Fig. 2 the H1 result is compared with the result of several other experiments [9]. All radii are about the same, except for the MARK II measurement.

The radius shows no dependence on the type of interaction and on the total CMS energy, consistent with the string fragmentation model interpretation.

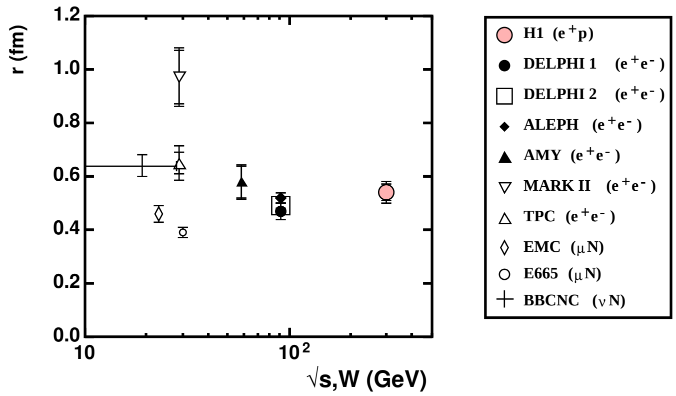

FIGURE 2. The radius r in the Gausian parameterization for various experiments.

SUMMARY

The Bose-Einstein Correlations increase faster with decreasing T than a Gaussian. The exponential and the power-law parameterizations are valid alternatives to the traditional Gaussian parameterization. The Gaussian radius tends to increase with multiplicity but no evidence for dependence on x_{bj}, W, Q^2, total CMS energy or type of interaction has been observed.

REFERENCES

1. Hanbury-Brown R. and Twiss R.Q., *Phil. Mag.* **45**, 663 (1954); *Nature* **178**, 1046 (1956); *Nature* **178**, 1447 (1956).
2. Goldhaber G. et al., *Phys. Rev. Lett.* **3**, 181 (1959); *Phys. Rev.* **120**, 300 (1960).
3. Lörstad B., *Int. J. Mod. Phys.* **A4**, 2861 (1989); Boal D. et al., *Rev. Mod. Phys.* **62**, 553 (1990); Quebert J., *Ann. Phys. Fr.* **17**, 99 (1992).
4. Andersson B. et al., *Particle World* **2**, 1 (1991); *Phys. Lett.* **B169**, 364 (1986).
5. De Wolf E.A. et al., *Phys. Rep.* **270**, 1 (1996).
6. Białas A., *Nucl. Phys.* **A545**, 285c (1992).
7. Adloff C. et al. (H1-Coll.), DESY-Preprint 97-075 (1997).
8. Abt I. et al. (H1-Coll.), *Nucl. Instr. Meth.* **A386**, 310 (1997); **A386**, 348 (1997).
9. Abreu P. et al. (DELPHI-Coll.), *Phys. Lett.* **286**, 201 (1992);
Decamp D. et al. (ALEPH-Coll.), *Z. Phys.* **C54**, 75 (1992);
Choi S.K. et al. (AMY-Coll.), *Phys. Lett.* **355**, 406 (1995);
Juričič I. et al. (MARK II-Coll.), *Phys. Rev.* **D39**, 1 (1989);
Aihara H. et al. (TPC-Coll.), *Phys. Rev.* **D31**, 406 (1985);
Arneodo M. et al. (EMC-Coll.), *Z. Phys.* **C32**, 1 (1986);
Adams M.R. et al. (E665-Coll.), *Phys. Lett.* **308**, 418 (1993);
Korotkov V.A. et al. (BBCNC-Coll.), *Z. Phys.* **C60**, 37 (1993).