BOSE–EINSTEIN CORRELATION STUDIES AT HERA-B*

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(Received December 1, 2004)

The potential for two-particles correlation studies is investigated using data collected by the HERA-B experiment. HERA-B is a fixed-target multi-particle spectrometer experiment operating at the 920 GeV HERA proton beam at DESY. The minimum bias data sample from the 2002/2003 HERA run, consisting of 200 million interactions recorded with a minimum bias trigger, provides the opportunity of determining the Bose–Einstein correlation function parameters for both pion and kaon pairs. Preliminary results, for pions, are presented.

PACS numbers: 13.90.+i, 13.85.Hd

1. Introduction

During the 50-ies, in particle physics experiments and in the astronomical observations, it was discovered that bosons emitted from the same source show the tendency to have similar energy-momentum characteristics [1, 2]. This phenomenon of increasing probability for the emission of identical bosons from close regions of space and time is called Bose–Einstein Correlation (BEC).

Presuming that only particles emitted from the same or very close sources are produced with small relative momentum, high energy heavy ion collision experiments developed precise methods, using boson interferometry studies, to obtain information about the shape of the region in which the detected particles are produced and to analyze its spatial and temporal characteristics.

* Presented at the XXXIV International Symposium on Multiparticle Dynamics, Sonoma County, California, USA, July 26–August 1, 2004.

HERA-B experiment ([3,4]) provides a unique opportunity to perform BEC studies, at a center of mass energy of $\sqrt{s} = 41,6$ GeV, intermediate between the center of mass energies where the SPS and RHIC experiments provide results. The multi-wire target system give the possibility of studying the BEC parameters dependence on the target material (C, Ti, W). The rich minimum bias sample, 103 million pC events, 74 million pW events, 28 million pTi events, and the large acceptance at midrapidity ($x \in (15, 220)$ mrad, $y \in$ (15–160) mrad) allow us to study the shape of the region where the bosons are produced, the multiplicity and transverse mass dependence of BEC function parameters. Both pions and kaon pairs can be used for some of these studies. This article is presenting only a feasibility study, made on a small sample (few million events).

2. Bose–Einstein correlations

Considering the production of two identical bosons with four-momenta p_1 and p_2, the BEC function C_2 is defined as:

$$C_2(p_1, p_2) = \frac{P(p_1, p_2)}{P(p_1)P(p_2)} \,, \tag{1}$$

where $P(p_1, p_2)$ is the probability density of two particles to be produced, and $P(p_1)$ and $P(p_2)$ — the probability densities for a single particle to be produced with four-momentum p_1 or p_2. In practice, it is difficult to construct the product $P(p_1)P(p_2)$, therefore, it is often replaced by a "reference sample", that must contain all the features which are present in the distributions constructed for identical pairs in data, except the Bose–Einstein symmetry, and must not contain additional features.

Here the reference sample pairs are built using a track from the current event and a randomly picked track from a reference buffer of events, continuously updated. The mixing procedure does not conserve energy and momentum, and destroys not only the Bose–Einstein correlation but even some other kinds of correlations. To eliminate side effects introduced by mixing we divide our correlation function:

$$C_2(Q) = \frac{N_{\rm data}(Q)}{N_{\rm data}^{\rm MIX}(Q)}\,, \qquad Q = p_1 - p_2\,, \tag{2}$$

with a correction coefficient $c(Q)$

$$c(Q) = \frac{N_{\rm MC-BEoff}(Q)}{N_{\rm MC-BEoff}^{\rm MIX}(Q)}\,, \tag{3}$$

where the distributions $N_{\mathrm{MC-BEoff}}(Q)$ and $N^{\mathrm{MIX}}_{\mathrm{MC-BEoff}}(Q)$ are obtained using standard HERA-B Monte Carlo, without BEC effects included in the simulation.

Also, to correct the correlation function for the Coulomb interaction between the pions we weighted it with the Gamow factor

$$G(\eta) \sim \frac{\eta}{e^{\eta}-1}\,, \qquad \eta = \frac{2\pi\alpha m_{\pi}}{Q}\,. \tag{4}$$

The BEC is generally parameterized as a function of the difference in the two particle four-momenta Q

$$C_2(Q) = N\left(1+\lambda\, e^{-Q^2R^2}\right)(1+\delta\, Q)\,, \tag{5}$$

where λ is related to the fraction of identical bosons which do interfere, R is usually interpreted as the geometrical radius of the presumably spherical boson emitting source, N is a normalization constant and $(1+\delta\, Q)$ is describing the linear background.

3. HERA-B experiment

The HERA-B spectrometer ([3,4]), is a forward spectrometer, with large angular acceptance. Eight target wires (see Fig. 1 right)) made of C, Ti, W, Pd, Al can be inserted independently in the halo of HERA proton beam. For this study only single wire runs were used.

The tracking of particles coming from the interaction of the proton with the target wire is done in the region before the magnet (see Fig. 1), using the information provided by a Silicon Vertex Detector (VDS). VDS is built of 64 double-sided silicon micro-strip detectors arranged in eight superlayers (SI01–SI08) each divided in quadrants. A quadrant consists of two double sided silicon layers housed in a “Roman pot”, allowing the detectors to retract

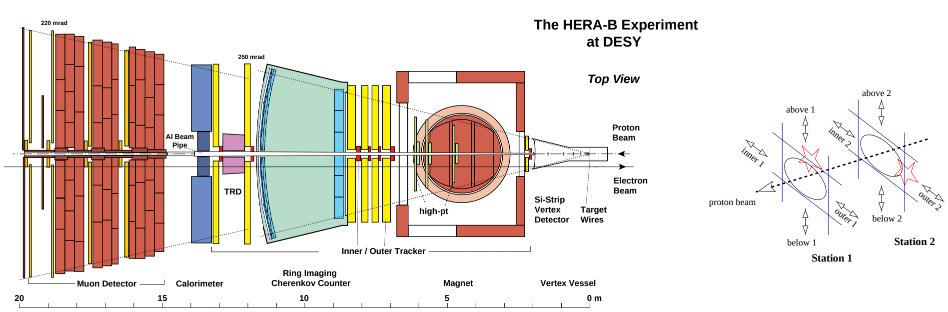


Fig. 1. HERA-B detector.

during injection (except SI08). A single superlayer provides measurements with stereo angles of $-2.5°$, $+2.5°$, $-87.5°$ and $92.5°$ relative to the y-axis.

In the region behind the magnet tracking is performed using the Outer Tracker (OTR) information. Each OTR superlayer contains several layers with angles of $0°$ and $\pm 5°$. Due to the large size of the OTR, one superlayer is built from many modules. Each layer is composed of honeycomb drift cells, the cell size being 5 mm in modules closest to the beam pipe and 10 mm further away.

Particle identification, for the present analysis, is provided by a large Ring Imaging Cherenkov Detector (RICH), filled with C_4F_{10}. The Cherenkov photons are reflected, by a series of mirrors, to multi-channel photomultipliers placed outside the detector acceptance. Pions and kaons can be separated up to momentum of about 60 GeV.

4. Preliminary results

The results presented here are obtained analyzing a small sample of 2002/2003 minimum bias, single wire events (few millions). Only pion tracks that gave signal in the HERA-B detector all the way from the VDS to the RICH were used. Based on our knowledge related to the spatial and momentum resolution of our detector, we eliminated from the analyzed sample, the pairs of tracks too close in space and momentum to be resolved by our reconstruction chain

$$|tx_1 - tx_2| < 0.0008 , \qquad tx = px/pz , \tag{6}$$
$$|ty_1 - ty_2| < 0.0008 , \qquad ty = py/pz , \tag{7}$$
$$|p_1 - p_2| < 0.0008 , \qquad p = |\vec{p}\,| . \tag{8}$$

Equivalent cuts were applied to the mixing sample and to the Monte Carlo sample used for the correction coefficient Eq. (3). The $C_2(Q)$ distributions for pions were corrected for Coulomb interaction (Gamow) only small variation in the BEC parameter values, λ, R, occurring.

The experimental procedure, mixing and corrections, were checked by measuring the parameters of the BEC function, introduced in the HERA-B Monte Carlo pC sample, obtained by using the JETSET BEC implementation [5]. Based on the MC truth information, the same sample was used to check the influence of the non-belonging pairs, pairs in which at least one particle is not a pion (a junk, a kaon a proton *etc*). Even if further systematic error studies will be necessary after running on the full sample, the above studies proved that we recover the input BEC function parameters correctly and the influence of the non-belonging pairs, that were not eliminated by our cuts, is negligible in the limit of the present statistical errors.

The results obtained by fitting the BEC function, as described above, with Eq. (5), coming from the pC, pTi, pW interactions are presented in the Table I and Fig. 2. These results, are very much dependent on the fit range. This is an expected behavior given the fact that the Gaussian is only an approximation based on the assumption of a spherical region in which the pions are produced [6]. Comparing the parameter values, obtained for different targets, for any of the quoted fit ranges, one can see a weak dependence on the target material if any. This is confirming the previous results of Na44 [7] and WA80 [8].

TABLE I

Dependence of BEC function parameters λ and R, on the target material and the fit range.

Target		Q < 1.2 GeV	Q < 0.72 GeV	Q < 0.36 GeV
Carbon	λ	0.288±0.013	0.275 ± 0.016	0.183± 0.035
	R(fm)	1.003 ± 0.042	1.057 ± 0.058	1.347 ± 0.143
	χ^2	106/95	74/55	36/25
Titanium	λ	0.207 ± 0.014	0.253 ± 0.020	0.223 ± 0.032
	R(fm)	0.903 ± 0.050	1.298 ± 0.097	1.849 ± 0.259
	χ^2	127/95	68/55	24/25
Tungsten	λ	0.305± 0.018	0.293±0.021	0.242 ± 0.042
	R(fm)	1.133 ± 0.055	1.307 ± 0.076	1.525± 0.177
	χ^2	130/95	62/55	35/25

Our statistics allows multi-dimensional fits which are more sensitive to interesting dynamics, less influenced by relativistic effects, and more plausibly related to the emission volumes (as a consequence of being less dependent on the fit range) than the one-dimensional approach, where Q represents an average over all the directions of the pairs within the acceptance of the experiment. For such kind of multi-dimensional studies, the so-called Longitudinal Centre-of-Mass System (LCMS) (see Fig. 3 left) is frequently used. The LCMS is defined for each pair of particles as the system in which the sum of the two particle momenta is perpendicular to a selected reference axis, in our case, the beam axis. In such a system, Q is decomposed into: $Q_{\rm long}$, parallel to the beam axis; $Q_{t,\,\rm out}$, collinear with the sum of the two particles momenta, and the complementary $Q_{t,\,\rm side}$, perpendicular to both $Q_{\rm long}$ and $Q_{t,\,\rm out}$. This system is convenient for calculations and interpreta-

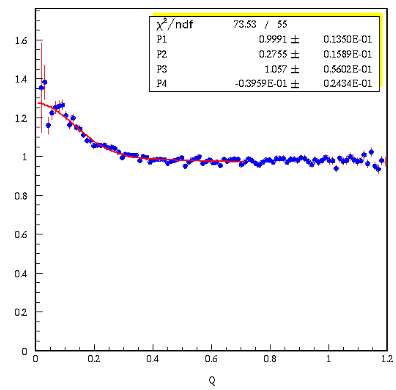


Fig. 2. One-dimensional BEC function.

tions since the spatial dimensions of the source affect all components of Q but the energy difference and hence the temporal dimension of the source is coupling only to the $Q_{t,\,\text{out}}$

The two-dimensional projection of the LCMS is often used in analysis, with longitudinal component $Q_{\|} \equiv Q_{\text{long}}$ and perpendicular component $Q_{\perp} = \sqrt{Q^2_{t,\,\text{out}} + Q^2_{t,\,\text{side}}}$, the parameterization of C_2 in the two-dimensional case becoming:

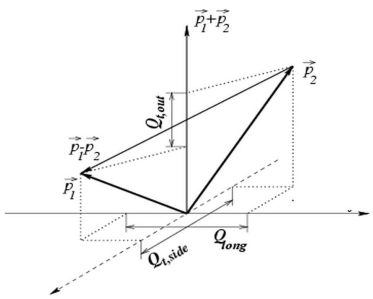
$$C_2(Q_{\perp}, Q_{\|}) = 1 + \lambda e^{-Q^2_{\perp} R^2_{\perp} - Q^2_{\|} R^2_{\|}} \,. \tag{9}$$

The results of the fit of the two-dimensional correlation function, for pC interaction, obtained using the double differential distributions, following the same procedure as for the one-dimensional BEC, are presented in Fig. 3. The results are in accord with the Na44 results [9], the two components of the radius being almost equal and both of them larger than the radius of the interacting particles. The large sample of kaons provided by our experiment will allow us to study the BEC also for pairs of kaons, some very preliminary results, on a sample of about 18 million events, indicating, as it was expected [10], that the radius for kaons is smaller, about one half from the pion radius.

5. Summary and plans

BEC were observed for both $\pi\pi$ and KK pairs. One-dimensional BEC parameters were estimated for pairs of pions in the pA interaction with A =C, Ti, W and two-dimensional BEC (pC). The very first preliminary results are presented here.

There is still a lot to be done in terms of running over all the data set, careful study of systematic errors, understanding the results and comparing them quantitatively not only qualitatively with other experimental results.



$$\begin{aligned}\lambda &= 0.26 \pm 0.01\\ R_{\mathrm{L}}(\mathrm{fm}) &= 0.89 \pm 0.03\\ R_{\mathrm{T}}(\mathrm{fm}) &= 1.05 \pm 0.04\end{aligned}$$

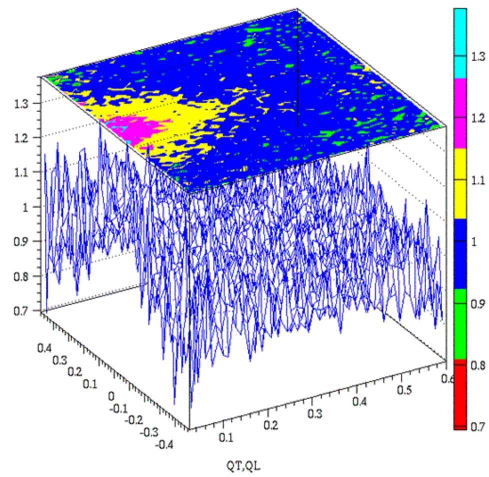


Fig. 3. The LCMS reference system and the two-dimensional BEC function fit results, 5.5 million events.

Studies of the three-dimensional BEC parameters and on the multiplicity and of their dependence on the transverse mass of the pair of particles are also possible, the code is written and the data are available.

We are convinced that HERA-B is the place to do interesting studies of BEC and we are looking forward to our further results.

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