BOSE-EINSTEIN CORRELATIONS BETWEEN KAONS

The Axial Field Spectrometer Collaboration

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ABSTRACT

Bose-Einstein correlations between identical charged kaons are observed in $\alpha\alpha$, pp , and $p\bar{p}$ collisions at the CERN Intersecting Storage Rings. The average radial extension of the K-emitting region is found to be (2.4 ± 0.9) fm. It increases with multiplicity in a similar fashion to that for pion emission.

(Submitted to Physics Letters B)

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1. INTRODUCTION

Bose-Einstein correlations between identical bosons emitted from high-energy hadron collisions are well established for pions [1]. The effect is an enhanced probability for identical bosons to be emitted with small relative momenta, compared with an uncorrelated case. The origin of this effect lies in the quantum mechanical requirement of a symmetrized wave function for bosons. It is the quantum mechanical analogue of the correlation between photons, responsible for the Hanbury-Brown-Twiss effect, which is used in astronomy to measure the size of stellar objects [2]. In particle physics it allows a determination of the size of the boson-emitting region. The theory has been developed, for example in reference [3], and evidently it is valid not only for pions but also for all kinds of bosons and in particular for kaons.

Earlier work on this topic ($K_S^0 K_S^0$) has been reported elsewhere [4]. In this paper we present the first study using charged kaons, based on data from $\alpha\alpha$, pp , and $p\bar{p}$ collisions collected with the Axial Field Spectrometer (AFS) at the CERN Intersecting Storage Rings (ISR). Our aim is to confirm the existence of a positive correlation between identical charged kaons as well as to measure the corresponding size of the emitting region. Furthermore, a comparison is made with $\pi\pi$ correlations obtained from a subsample of the same data, and the dependence on mean charged-particle multiplicity is examined. Finally, results are presented concerning combinations of equally charged kaons and pions, for which the Bose-Einstein correlations must be absent.

2. EXPERIMENTAL SET-UP, DATA, AND DATA ANALYSIS

The data used in this analysis were obtained with the AFS, which is described in detail elsewhere [5]. The analysis relies on the cylindrical drift chamber that surrounded the interaction region and was used to measure the vertex and track information for charged particles. In the transverse plane the chamber is divided azimuthally into sectors of 4° , each containing 42 sense wires radially distributed at distances between 0.2 and 0.8 m from the centre. Position coordinates in the plane transverse to the sense wires are determined from the drift time and have a resolution of $\sim 230 \mu\text{m}$. Along the wires, parallel with the beams, positions are measured from the relative pulse heights at both ends of each wire. The corresponding resolution is $\sim 1.5 \text{ cm}$. The pulse-height measurements also provide dE/dx information which is used for particle identification. The rapidity range covered by the detector is $|y| \leq 1.0$.

The data were processed through standard track-finding, vertex reconstruction, and momentum determination programs, and were subjected to several quality restrictions. Apart from the $\Delta p/p$ requirement, which it was found possible to relax from ≤ 0.04 to ≤ 0.10 , these cuts are described in ref. [6]. Special attention had to be paid to particle identification, which was obtained by utilizing the different linear relations between dE/dx and $1/p^2$ for the various particle types (see fig. 1). For kaons, a (π, p) contamination of $\sim 5\text{--}10\%$ was accepted, whereas the pion sample is contamination-free. A portion of the data was obtained using a high charged-multiplicity trigger which gave 23,000 $\alpha\alpha$ events at $\sqrt{s} = 126 \text{ GeV}$ and 24,000 pp events at $\sqrt{s} = 63 \text{ GeV}$. The remainder of the data was obtained with a minimum bias trigger, and consists of 40,000 $\alpha\alpha$ events at $\sqrt{s} = 126 \text{ GeV}$, 150,000 pp and 90,000 $p\bar{p}$ events at $\sqrt{s} = 53 \text{ GeV}$, and finally 117,000 pp events at $\sqrt{s} = 63 \text{ GeV}$. In the study of KK and $\pi\pi$ correlations, only events with at least two kaons or pions, respectively, were accepted. For the kaons, this gave 11,375 particles distributed among 5241 events, and for the pions, 89,731 particles among 26,956 events. The corresponding requirement imposed for the $K\pi$ investigation was to ask for events with at least one K and one π . This gave 11,353 events. The $\pi\pi$ as well as the $K\pi$ samples were selected to have a composition similar to that of the total data sample as far as the triggers were concerned.

The data are presented as a ratio between the actual distribution of particle pairs and a corresponding uncorrelated distribution. In theories with point-like, massive, and independent

sources (see, for example, ref. [3]) this ratio has been parametrized in terms of a Bessel function, and for pairs of identical particles [6] it is given as

$$R = 1 + \lambda [2J_1(q_T r)/q_T r]^2 \{1/[1 + (q_L \tau c)^2]\} . \quad (1)$$

Here J_1 is the first-order Bessel function, q_T is the component of $\vec{p}_1 - \vec{p}_2$ transverse to $\vec{p}_1 + \vec{p}_2$, and q_L is the component of $\vec{p}_1 - \vec{p}_2$ parallel to $\vec{p}_1 + \vec{p}_2$; r is interpreted as the radius of a sphere, from the surface of which the interfering particles are emitted by uniformly distributed sources; τ in some models represents the lifetime of these sources, whereas in others it is ascribed to the depth of the emission layer; c is the speed of light; λ takes into account that the interference is not complete.

In this analysis the uncorrelated distribution is formed by pairing particles from different but consecutive events, in the series of data. For pairs from the same (S) event as well as from different (D) events, a (q_T, q_L) binning was made, and the ratio S/D versus (q_T, q_L) was formed. The ratio was normalized to the same number of entries in the region $q_L \leq 0.30$ GeV/c and $q_T \geq 0.40$ GeV/c. This choice was suggested by the shape of the ratio function, which indicates that no correlations are present here. To take into account the limited two-track resolution of the drift chamber, minimum opening angles $|\Delta\theta^{\text{cm}}|$ and $|\Delta\phi^{\text{cm}}|$ of 2.5° were required for pairs from the same event as well as from different events. For the uncorrelated distribution, in order to avoid combining particles from events with very different multiplicities, the low and high tails of the charged-particle multiplicity distributions were excluded. All values of the mean charged multiplicity $\langle n_{\text{ch}} \rangle$ quoted below refer to these truncated distributions. The truncations were performed for each data set, characterized by trigger and incident particle types.

In order to improve statistics for the KK correlations, the following special steps were taken (which, for reasons of compatibility, were applied also to the $\pi\pi$ correlations): i) Positively and negatively charged combinations were added (from the results of ref. [6] we have no reason to assume any charge dependence). ii) Data from different samples were added. In justifying this we rely on ref. [6], where no dependence on incident particle type was found. iii) The size of the lower bins of q_T was increased from 0.05 GeV/c to 0.10 GeV/c.

3. RESULTS

As a first step we set out to establish the existence of a positive correlation for identical charged kaons. In doing this, the following ratio, normalized as indicated above, was formed:

$$R = \{ (++)^S + (--)^S \} / \{ (++)^D + (--)^D \} , \quad (2)$$

where S refers to the total number of ‘same-event’ combinations in some particular bin of (q_T, q_L) , and D to the corresponding number of ‘different-event’ combinations. Also indicated are the electric charges of the particles. The ratio $R(\text{KK})$ versus q_T is shown in fig. 2 for $q_L \leq 0.30$ GeV/c and all data samples. It shows a clear positive correlation for $q_T \leq 0.20$ GeV/c. This ratio R can be fitted in terms of the Bessel function in eq. (1), which for fixed q_L reads

$$R = 1 + \lambda' [2J_1(q_T r)/q_T r]^2 , \quad (3)$$

where $\lambda' = \lambda/[1 + (q_L \tau c)^2]$. The fitted parameters are $r = (2.4 \pm 0.9)$ fm and $\lambda' = 0.58 \pm 0.31$, with a $\chi^2/\text{d.o.f.}$ of 1.32/3. The fit, also displayed in fig. 2, was performed for $q_T \leq 0.50$ GeV/c and $q_L \leq 0.30$ GeV/c.

For reasons of comparison, a $\pi\pi$ analysis based on a subsample of the same data as those used for the KK correlation was performed. This was, to a large extent, a repetition of the

analysis in ref. [6], but with the special steps described above and making use of the dE/dx method for pion identification. In ref. [6] it was found that $r(\pi\pi)$ increases with increasing mean charged-particle multiplicity, independently of the incident particle type. This has been given a theoretical interpretation by Barshay [7], by relating r to the size of the overlapping region of the two colliding particles: a large overlap should imply a large $\langle n_{ch} \rangle$. To investigate whether there exists a similar dependence for kaons, the data were grouped into two samples: i) high multiplicity, $\alpha\alpha$; and ii) the remainder. In the pion case, the data were divided into three sets. For each of these subsamples a fit to eq. (3) was performed. Values of the fitted parameters are quoted in table 1 and illustrated in fig. 3. We find $r(KK) \leq r(\pi\pi)$. This is consistent with the indications given by the authors of ref. [4], who find a smaller radius for KK than for $\pi\pi$. Furthermore, a rise of $r(KK)$ with $\langle n_{ch} \rangle$, similar to that of $r(\pi\pi)$, is indicated.

In connection with Bose-Einstein correlations, it is also interesting to study combinations of non-identical bosons that are expected to exhibit neither Bose-Einstein symmetrization nor resonance contributions, e.g. $K^+\pi^+$ and $K^-\pi^-$. Therefore such an investigation was carried out along the same lines as for KK and $\pi\pi$, but normalized to the same total number of S and D combinations in the range $q_L \leq 0.30$ GeV/c. The following ratio was formed:

$$R = \{(K^+\pi^+)^S + (K^-\pi^-)^S\} / \{(K^+\pi^+)^D + (K^-\pi^-)^D\} . \quad (4)$$

The results, based upon 11,353 events from a representative subsample of the data, are shown in fig. 4. No correlation is seen. The data also rule out the predictions of a strong anticorrelation (claimed, for example, in ref. [8]) as the result of a dynamical suppression of neighbouring particles with exotic quantum numbers within one jet. The lack of correlation in this case may be considered as a check on the method used for KK , and lends support to the algorithm of combining particles from different events to form an uncorrelated reference distribution.

4. CONCLUSIONS

Bose-Einstein correlations between identical charged kaons have been observed and found to have the same qualitative features as $\pi\pi$ correlations. The spatial extension $r(KK)$ appears to increase with increasing mean charged-particle multiplicity in a similar way to that for $r(\pi\pi)$.

For pairs of non-identical bosons of the same charge, $K^+\pi^+$ and $K^-\pi^-$, no correlation is found.

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Table 1
Fit of the correlation data to a Bessel function ($q_L \leq 0.30$ GeV/c)

Data	$\langle n_{ch} \rangle$	r (fm)	χ'	$\chi^2/\text{d.o.f}$
KK: Total	10.5	2.4 ± 0.9	0.58 ± 0.31	1.32/3
KK: High mult., $\alpha\alpha$	15.6	2.2 ± 0.6	0.60 ± 0.28	0.35/3
KK: Tot - High mult., $\alpha\alpha$	6.4	1.0 ± 0.6	0.18 ± 0.15	2.37/3
$\pi\pi$: Min. bias, pp	4.0	1.5 ± 0.1	0.34 ± 0.04	1.44/3
$\pi\pi$: High mult., pp	8.2	2.1 ± 0.3	0.35 ± 0.06	3.67/3
$\pi\pi$: High mult., $\alpha\alpha$	14.5	2.6 ± 0.4	0.16 ± 0.04	6.73/3

Figure captions

- Fig. 1 : Scatter plot showing the linear relations between dE/dx and $1/p^2$ for different types of particles. The region where particles are identified as kaons is indicated. (Data from one sample of minimum bias, $\alpha\alpha$, and tracks with 20–29 pulse-height measurements.)
- Fig. 2 : $R(KK)$ as given by eq. (2), as a function of q_T for $q_L \leq 0.30$ GeV/c. All data samples are added. Also shown is the fitted Bessel function, eq. (3).
- Fig. 3 : The fitted parameters a) r and b) χ , from eq. (3), versus $\langle n_{ch} \rangle$ for KK (all data) and $\pi\pi$ (subsample) when the data are divided into samples with different $\langle n_{ch} \rangle$.
- Fig. 4: $R(K\pi)$ as given by eq. (4) as a function of q_T for $q_L \leq 0.30$ GeV/c, based upon a representative subsample of the data.

Fig. 1

Fig. 2

Fig. 3

Fig. 4