BOSE-EINSTEIN CORRELATIONS IN $\alpha\alpha$, pp AND $p\bar{p}$ INTERACTIONS

The Axial Field Spectrometer Collaboration

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ABSTRACT

Bose-Einstein correlations between pions produced in the central region of rapidity in $\alpha\alpha$, pp and $p\bar{p}$ interactions have been studied at the ISR. The parameters r and τ_c - often interpreted as the radius and depth of the π -emitting region - are found to be independent of incident particle type but to depend on the mean charged multiplicity. In high multiplicity events, the pions appear to originate from a larger space-time region.

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Bose-Einstein correlations, arising from the interference between wave functions of identical bosons, manifest themselves as an increased probability for two or more bosons to be emitted with small relative momenta, compared to what is expected for non-identical particles under the same conditions. From the interference pattern, the dimensions of the boson emitting source are, in principle, determinable. It was shown already by R. Hanbury-Brown and R.Q. Twiss [1] that the effect is present in the case of photons originating from stellar objects. The extension of the phenomenon to high energy physics was confirmed by G. Goldhaber, S. Goldhaber, W. Lee and A. Pais [2] and has been discussed by several authors [3]. Since then, the concept of heavy ion collisions has opened up new fields of Bose-Einstein interferometry to be investigated.

In a model with independent, massive and pointlike π -emitting sources, uniformly distributed over the surface of a sphere of radius r and with oscillator lifetime τ , the emission rate for two pions, compared to the uncorrelated case, can be expressed (cf. e.g. [4]):

$$R = 1 + \left[\frac{2J_1(q_T r)}{q_T r} \right]^2 \cdot \frac{1}{1 + (q_0 \tau)^2} \quad (1)$$

where J_1 is the 1st order Bessel function, $q_0 = |E_1 - E_2|$ and q_T is the component of $\vec{p}_1 - \vec{p}_2$ transverse to $\vec{p}_1 + \vec{p}_2$. An alternative interpretation, proposed by G. Cocconi [4], identifies τ with the depth of the π -emitting region. In the case of relativistic pions with small opening angles, q_L , defined as the component of $\vec{p}_1 - \vec{p}_2$ parallel to $\vec{p}_1 + \vec{p}_2$, is a good approximation to q_0 . In order to allow for the possibility of non-independent sources, the degree of incoherence, λ , has been introduced [5] ($\lambda \rightarrow 1$ in the case of fully independent emission). The final parametrization of R used in this analysis reads:

$$R = 1 + \lambda \left[\frac{2J_1(q_T r)}{q_T r} \right]^2 \cdot \frac{1}{1 + (q_L \tau_c)^2} \quad (2)$$

The data were collected with the Axial Field Spectrometer (AFS) at the CERN ISR. The experimental set-up is described in [6]. For this study we used the central vertex detector - a cylindrical drift chamber - surrounding the interaction region. 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 determined from the relative pulse heights measured at both ends of each wire. The corresponding resolution is $\sim 1.5 \text{ cm}$. The pulse height measurements also provide dE/dx information, used for particle identification.

The data consist of 19 000 $\alpha\alpha$ -events at $\sqrt{s} = 126 \text{ GeV}$ and 20 000 pp-events at $\sqrt{s} = 63 \text{ GeV}$, triggered on high charged multiplicity, and 28 000 $\alpha\alpha$ -events at $\sqrt{s} = 126 \text{ GeV}$, 91 000 pp- and 113 000 $p\bar{p}$ -events at $\sqrt{s} = 53 \text{ GeV}$, all with a minimum bias trigger.

After being processed through standard tracking, vertex reconstruction and momentum determination programs for charged particles in the drift chamber, some restrictions were imposed on the data in order to obtain a good quality of the events and the tracks associated with them. Events with no reconstructed vertex within the interaction region were rejected as well as those which had a poor vertex fit. Accepted tracks were required to have $\Delta p/p \leq 0.04$ and $p_T(\text{LAB}) \geq 0.10 \text{ GeV}/c$. Cuts on χ^2/NDF for each track and for its fit to the vertex were also imposed. The rapidity range covered was $|y| \leq 1.0$. In order to deal properly with Bose-Einstein correlations some special steps were taken: All particles not unambiguously identified by dE/dx as K, p or $\bar{p}$, were treated as pions in the analysis. The limited ability to separate close tracks in the drift chamber implied a cut in the relative angles for every pair of particles ($|\Delta\theta| \geq 2.5^\circ$ and $|\Delta\phi| \geq 2.5^\circ$). An uncorrelated background was formed by combining particles, from events adjacent in the sequence of data, in pairs, and to get comparable acceptances, the same requirement was imposed also on these "mixed-event" pairs. The tails of the multiplicity distributions were excluded from the analysis so as to avoid combining pions that originated from events with widely different multiplicities. $\langle n_{\text{ch}} \rangle$ below, refers to these truncated distributions of charged particles.

We now turn to expressing $R(q_T, q_L)$, as given by (2), in terms of experimentally obtainable quantities. For each pion pair the previously defined q_T and q_L were calculated, using momenta transformed to the CM-system. Then, for each (q_T, q_L) -bin, the ratio between the total number of pairs in the same and in different events was formed. The question of normalization now arises and deserves some attention. As a preparatory step, the background was normalized to the same total number of pairs. However, in the presence of correlations, $R \neq 1$ as q_T or $q_L \rightarrow \infty$, but from the shape, rather than from the level of the curve, it was possible to establish limits of q_T and q_L above which Bose-Einstein correlations were certainly not observed. Making use of this, the background was then normalized to the same number of pairs in the correlation free region defined by $q_T \geq 0.6 \text{ GeV/c}$ or $q_L \geq 0.6 \text{ GeV/c}$. The accordingly calculated $R(q_T, q_L)$ were fitted to the parametrization in (2). The fit extended over the full (q_T, q_L) -plane within the correlation region and was performed for each data set, characterized by trigger, incident particle type and mean charged multiplicity $\langle n_{ch} \rangle$. As an example, $R(q_T)$ with $q_L \leq 0.15 \text{ GeV/c}$, and $R(q_L)$ with $q_T \leq 0.15 \text{ GeV/c}$, for the pp minimum bias data, are shown in Figs. 1a and 1b. (Although statistics are rather poor for these bins, the data were checked and in general, to a good approximation, found consistent with a Gaussian behaviour.) Also shown is the fitted function for these particular bins with the parameters obtained from the global fit.

The values of r and τ_c were found to increase with increasing $\langle n_{ch} \rangle$, whereas no systematic dependence upon the identities of the incident particles was found apart from that implied by different mean multiplicities. This is illustrated in Fig. 2 where r and τ_c are plotted against $\langle n_{ch} \rangle$. In particular r and τ_c for fixed $\langle n_{ch} \rangle$ are the same for pp collisions and $\alpha\alpha$ collisions. Earlier investigations of collisions between heavy nuclei have led to larger values of r , as expected [7]. The incoherence parameter λ seems to decrease with increasing $\langle n_{ch} \rangle$ as shown in Fig. 3. We observe no statistically significant differences between $\pi^+\pi^+$ and $\pi^-\pi^-$ combinations.

The dependence of r and τ_c on $\langle n_{ch} \rangle$, which is observed here for the first time, indicates a pion emitting region increasing in size with the number of pions emitted.

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FIGURE CAPTIONS

- Fig. 1 (a) $R(q_T)$ with $q_L \leq 0.15$ GeV/c and (b) $R(q_L)$ with $q_T \leq 0.15$ GeV/c for $\pi^+\pi^+$ in pp, minimum bias. The fitted function (2), for these particular bins and with parameters obtained from the global fit, is also shown. $r(++) = (1.2 \pm 0.1)\text{fm}$, $\tau_c(++) = (0.9 \pm 0.2)\text{fm}$ and $\lambda(++) = 0.43 \pm 0.06$.
- Fig. 2 The parameters (a) $r(++)$, (b) $\tau_c(++)$, (c) $r(--)$ and (d) $\tau_c(--)$ obtained from fitting the different data sets, displayed against the mean charged multiplicity $\langle n_{ch} \rangle$.
- Fig. 3 Fitted values of the degree of incoherence λ for (a) $\pi^+\pi^+$ and (b) $\pi^-\pi^-$ combinations.

Fig. 1

Fig. 2

Fig. 3