NEW BOSE-EINSTEIN RESULTS FROM L3

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In hadronic Z decays, we compare Bose-Einstein correlations in π⁰ pairs with those in identical charged pion pairs. We also measure Bose-Einstein correlations in triplets of identical charged pions. From the first study, the source radius is found to be smaller for π⁰−π⁰ than for π±−π±, as would be expected, e.g., in a string model. However, the second study shows that the data are consistent with the pion production being completely incoherent. Both studies use data collected by the L3 collaboration at LEP.

1 Introduction

Two studies of Bose-Einstein correlations (BEC) are reported using hadronic Z decays detected by L3 at LEP. The first uses two-particle BEC to compare the size of the emission region of π⁰ to that of π±. The second uses three-particle BEC to investigate the incoherence of pion emission. Neither of these topics has previously been investigated in e⁺e⁻ interactions.

2 Comparison of BEC in π⁰−π⁰ and π±−π±

Since this work is completed and the paper accepted for publication, I only summarize it briefly here. The analysis uses a data sample of about 2 million hadronic Z decays corresponding to about 78 pb⁻¹. Making use of the correlation function,

\[ R_2(Q) = \frac{\rho_2(Q)}{\rho_0(Q)} \]

where \(\rho_2\) is the number density of pion pairs for the data and \(\rho_0\) is the number density expected in the absence of BEC, both as a function of the four-momentum difference, \(Q\), between the two pions making up the pair. Under the simplified assumptions of a static, spherical source with a Gaussian density, \(R_2\) can be parametrized as

\[ R_2(Q) = \mathcal{N}(1 + \alpha Q)(1 + \lambda e^{-Q^2 R^2}) \]

where \(\mathcal{N}(1 + \alpha Q)\) serves as normalization, taking into account some long-range correlation in \(Q\). The factor \(\lambda\) is equal to unity if pion production is
incoherent and all pions come from the hypothesized source. The latter is
certainly not the case because of long-lived resonances, and usually \( \lambda \) is found
to be less than unity. With event and particle selection kept as identical as
possible for \( \pi^0-\pi^0 \) and \( \pi^\pm-\pi^\pm \), and using \textsc{jetset} without any BEC simulation
to determine \( \rho_0 \), fits of (2) result in a smaller radius for \( \pi^0-\pi^0 \) than for \( \pi^\pm-\pi^\pm \):
\[
R_{00} - R_{00} = 0.15 \pm 0.08 \pm 0.07 \text{ fm}
\]
\[
R_{00} / R_{\pm\pm} = 0.67 \pm 0.16 \pm 0.15
\]

3 Three-particle BEC

This analysis is preliminary and at present makes use of a sample of about
1 million hadronic Z decays. Similarly to the two-particle case, we use the
correlation function,
\[
R_3(Q) = \frac{\rho_0(Q_3)}{\rho_0(Q_3)}
\]
where \( Q_3^2 = M_{123}^2 - 9m^2_{\pi} = Q_{12}^2 + Q_{23}^2 + Q_{13}^2 \) with \( Q_{ij} \) the four-momentum
difference between the two pions \( i \) and \( j \) of the triplet. There are contributions
to \( R_3 \) from two-particle BEC and from genuine three-particle BEC. With \( G \)
the Fourier transform of the source density,
\[
R_2(Q_{ij}) = 1 + \lambda |G(Q_{ij})|^2
\]
\[
R_{3}^{\text{non-gen}}(Q_3) = 1 + \lambda (|G(Q_{12})|^2 + |G(Q_{23})|^2 + |G(Q_{13})|^2)
\]
\[
R_{3}^{\text{gen}}(Q_3) = 1 + 2\lambda^{1.5} \text{Re}\{G(Q_{12})G(Q_{23})G(Q_{13})\}
\]
\[
R_3(Q_3) = R_{3}^{\text{non-gen}}(Q_3) + R_{3}^{\text{gen}}(Q_3) - 1
\]
Note that \( R_{3}^{\text{gen}} \) depends on the phase of \( G \), whereas \( R_2 \) and \( R_{3}^{\text{non-gen}} \) do not.
With \( G(Q_{ij}) = |G| \exp(\phi_{ij}) \) and \( \phi = \phi_{12} + \phi_{23} + \phi_{13} \), we see from (4) and
(5) that
\[
\cos \phi(Q_3) = \frac{R_{3}^{\text{gen}}(Q_3) - 1}{2\sqrt{(R_2(Q_{12}) - 1)(R_2(Q_{23}) - 1)(R_2(Q_{13}) - 1)}}
\]
Departure of \( \cos \phi \) from unity occurs if the pion source is asymmetric of if
the pion emission is (partially) coherent. Genuine three-particle BEC have
previously been observed in hadronic Z decay\footnote{\textsc{jetset}}. Our interest here is therefore
mainly to investigate whether \( \cos \phi = 1 \). To measure \( \cos \phi \), we must first
measure \( R_2 \) using (6): \( R_3 = \frac{\rho_3}{\rho_0} \) and \( R_{3}^{\text{non-gen}} = \frac{\rho_2\rho_2}{\rho_0} \) from which \( R_{3}^{\text{gen}} \) is found
using (6). Here \( \rho_n \) refers to the \( n \)-particle density and \( \rho_0 \) the corresponding
density of the ‘reference sample’, \textit{i.e.}, a sample without BEC. Then \( \cos \phi \) is
found from (8).
The reference sample is constructed using a mixing technique and corrected by Monte Carlo for non-BEC correlations. Correlations for detector acceptance and efficiency, also determined from Monte Carlo, are applied to the data. There are six different combinations of Monte Carlo programs used to determine these corrections. Differences in results using the different combinations are the dominant contribution to the systematic uncertainty. Further, the $Q$-distributions are corrected for Coulomb repulsion by weighting each pair of pions by the inverse Gamow factor. At very small $Q$, statistics are small and the corrections are large; accordingly the regions $Q < 0.16$ GeV and $Q < 0.08$ GeV are not used.

The resulting distributions of $R_2$ and $R_{3\text{gen}}$ are shown in Figs. 1 and 2, respectively. As found in previous studies, the Gaussian parametrization of $R_2$ is found to be inferior to a parametrization using the Edgeworth expansion about a Gaussian,

$$R_2(Q) = N(1 + \alpha Q) \left[ 1 + \lambda e^{-Q^2 R^2} (1 + \kappa H_3(\sqrt{2}Q)/6) \right]$$

where $H_3$ is a 3rd order Hermite polynomial and $\kappa$ a free parameter. Also $R_{3\text{gen}}$ is found to be better fit by an Edgeworth expansion than by a Gaussian parametrization. The result of this Edgeworth fit is shown in Fig. 2. Also shown is the expectation calculated from the result of the fit to $R_2$ together with the assumption $\cos \phi = 1$. It is seen that $R_{3\text{gen}}$ is well described by this assumption. The values of $\lambda$ and $R$ found in the Edgeworth fits are shown in Table 1. The values found in these fits agree. Fig. 3 shows the distribution of $\cos \phi$ found bin-by-bin from the Edgeworth fit to $R_2$ and the distribution of $R_{3\text{gen}}$. It is seen that $\cos \phi$ is consistent with unity over the entire range of $Q_3$.

| Fit to | $\lambda$ (fm) | $R$ (fm) |
|-------|----------------|----------|
| $R_2$ | $0.72 \pm 0.02 \pm 0.07$ | $0.73 \pm 0.02 \pm 0.04$ |
| $R_{3\text{gen}}$ | $0.72 \pm 0.04 \pm 0.07$ | $0.72 \pm 0.04 \pm 0.05$ |

4 Conclusions

The radius of the pion source found in BEC studies of neutral pions is smaller than that of charged pions. Studies of three-particle BEC show agreement with completely incoherent pion production. Naively, the first result is expected in string models, but the second result is surprising.
Acknowledgments

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References

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