Bose Einstein Correlations in π^0 π^0 and η η Pairs Produced in Z^0 Decays

M. Boutemeur, M. Binder, B. Bußmann, T. Christiansen, J. Dubbert, G. Duckeck, A. Leins, S. Lager, P. Mendez-Lorenzo, N. Nesvadba, O. Sahr, D. Schaile, R. Ströhmer, T. Trefzger, T. Unverhau, and C.F. Vollmer

The Bose-Einstein Correlations (BEC) effect is a result of Bose-Einstein statistics. It was introduced in meson spectroscopy as the GGLP effect named after the authors, G.Goldhaber, S.Goldhaber, W. Lee and A. Pais, of the observation [1] of the Bose-Einstein Correlations in π^+ π^+ and π^- π^- systems. The distributions of the opening angles between the momenta of pairs of like-sign pions were shifted towards smaller angle as compared to the corresponding distribution of unlike-sign pairs. The same effect was used earlier by the astronomers Handbury, Brown and Twiss to estimate radii of stars, thus the other synonym 'HBT effect' used sometimes in the literature. It is nowadays commonly called the BEC effect. In high energy physics, here e^+e^- collisions at LEP, the BEC effect is used to probe details of quark fragmentation and hadronisation which are of crucial interest in testing the Standard Model. These details would help for example in achieving a more precise measurement of the W boson mass or in better knowledge of several Quantum Chromo-Dynamics (QCD) observables. The models presently used are mainly the string and cluster models implemented in the Jetset and Herwig Monte Carlo generators. The two models, have major differences in the hadronisation scenarios but both are based on the parton shower fragmentation approach: Jetset uses a leading log perturbative calculation, and Herwig a next-to-leading log calculation. Numerous studies of BEC in identical boson pairs already exist, see for example [2] and the references therein. However, very few or none exist for π^0 or η pairs. On the one hand, the study of BEC in π^0 and in η pairs within the same analysis would allow to measure the dependence of the radius of the emitting source on the boson mass. The source radius was reported [3] recently to decrease with the boson mass while it was predicted to increase with the boson mass within the string model. On the other hand, the string Model [4] predicts a stronger BEC effect and a smaller effective hadronisation radius in π^0 π^0 system as compared to $\pi^\pm\pi^\pm$ system while other models predict the same source strength and size. Beside the experimental difficulties in π^0 and η reconstruction, both π^0 π^0 and η η systems offer the advantage of being free of Coulomb corrections.

The present analysis is based on the full hadronic event sample collected at centre-of-mass energies at and near the Z^0 peak by the OPAL detector from 1991 to 1995. This corresponds to about 4 million hadronic Z^0 decays. The π^0 and η mesons are reconstructed using their two photon decay mode [5] where only the Barrel part of the detector is considered. The reconstruction efficiencies are 22% for the π^0 meson and 8% for the η meson. The correlation function is taken as the ratio:

$$C(Q) = \frac{\rho(Q)}{\rho_0(Q)}$$

where Q is the Lorentz-invariant variable expressed in terms of the two boson four-momenta p_1 and p_2 as $Q^2 = -(p_1 - p_2)^2$, $\rho(Q)$ is the measured Q distribution of the two identical bosons and $\rho_0(Q)$ is the reference distribution that should contain all the correlations included in $\rho(Q)$ except for the BEC correlations. Among several methods that exist [2] for constructing the $\rho_0(Q)$ distribution. We choose the method that relies on data only: we restrict the data sample to select only two back-to-back hadronic jet events for which there are at least two reconstructed identical mesons (π^0 or η), the $\rho_0(Q)$ is then constructed with boson pairs in which one of the bosons is reflected through the origin from one jet to an other. Background contribution, mainly from wrongly reconstructed mesons is estimated with Monte Carlo simulation and subtracted from the measured distributions. The correlation function C(Q), corrected for detector acceptance and reconstruction efficiencies, is parametrised using the expression for a static sphere of emitters with a Gaussian density:

$$C(Q) = N(1 + \lambda e^{-(RQ)^2}).$$

Here λ is the strength of the correlation which equals zero for a fully coherent source, R (in GeV^{-1}) is the radius of the source and N a normalisation factor. We obtain the following preliminary results:

$$\begin{aligned} \pi^0\ \pi^0: &\ \lambda = 0.95 \pm 0.31; \quad R/\hbar c = 0.68 \pm 0.09 \text{ fm} \\ \eta\ \eta: &\ \lambda = 0.89 \pm 0.43; \quad R/\hbar c = 0.55 \pm 0.18 \text{ fm} \end{aligned}$$

The quoted errors are purely statistical. The full systematic error study , which is dominated by the method used to construct the reference distribution, is still under investigation. Taking into account the statistical errors only, our result is in agreement with the string model prediction for the radius of the emitting source in the π^0 π^0 system as compared to the $\pi^\pm\pi^\pm$ system. The LEP measured average value of the radius of the emitting source for the $\pi^\pm\pi^\pm$ is $R/\hbar c = 0.78 \pm 0.01$ fm. The radius of the source is compatible of being constant or decreasing with the hadron mass as already reported in [3]. This last statement, if confirmed after taking into account the full systematic errors, would be in contradiction with the string model prediction for which the source radius for η pairs should be larger than for π^0 pairs.

References

[1] G. Goldhaber, S. Goldhaber W. Lee and A. PAIS, Phys. Rev. **120** (1960) 1300
[2] The OPAL Collaboration, G. Abbiendi *et al.*., CERN-EP/99-163.
[3] G. Alexander and I. Cohen in: "Providence 99, QCD and multi-particle production", hep-ph/9909286.
[4] B. Anserson and M. Ringner, Nucl. Phys. **513** (1998) 625; K. Zalewski, to be published in the proceedings of the Montpelier QCD 2000 conference.
[5] The OPAL Collaboration, G. Abbiendi *et al.*, Eur. Phys. J. **C17** (200) 337