BOSE-EINSTEIN CORRELATIONS IN PION PRODUCTION AT TRISTAN

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Abstract

Measurement of Bose-Einstein correlations in the production of like-signed pion pairs has been made with the AMY detector at TRISTAN. An event sample of 10120 hadronic events with $\sqrt{s}$ ranging between 50 to 61 GeV was used. These measurements indicate a strength of the enhancement of λ = 0.61±0.07, with a typical correlation size of R_0 = 1.16±0.08 fm. This value of λ is consistent with measurements at lower energies; however, R_0 is somewhat larger than lower energy results have indicated.

1. Introduction

The first application of Bose-Einstein correlations to determine the size of a particle source was made with the intensity interferometer developed by Hanbury Brown and Twiss [1] who proposed to measure the size of distant stars by detecting correlations in the intensity of the light emitted by them. The method was first applied to particle physics by Goldhaber *et al.* in 1959 [2,3]. In the intervening years, the theoretical framework has been developed and the size of the interaction region has been measured by numerous experiments in high energy collisions between many different types of particles (see e.g. refs. [4-6]).

Bose-Einstein correlations arise because the wavefunctions of identical bosons are symmetric with respect to particle exchange. If the dimensions of a boson emitting source are very small compared to the distance between the source and a detector, two identical bosons that arrive at the detector are indistinguishable with respect to their origin. The probability of finding them in the same element of phase-space is greater than the probability of finding two non-identical particles. The interference pattern produced by incoherently emitted identical bosons can be related to the size of the source from which they were emitted.

This paper discusses the size of the interaction region in $e^+ e^-$ collisions at the centre of mass energies ranging from 50 to 61 GeV. We describe the analysis techniques in section 2 followed by experimental procedure in section 3. In section 4 we present the two body Bose-Einstein correlation, and finally section 5 summarizes our conclusion.

Keywords: Bose-Einstein correlation; Correlation size; Enhancement

2. Analysis Techniques

Two body Bose-Einstein correlation is studied by comparing the distribution of like-charged pion pairs with a distribution of reference sample pairs which are free of the Bose-Einstein correlation. The ratio of R of the like-pair distribution divided by a suitably normalized reference pair distribution is parameterized in terms of a Gaussian function of the four-momentum difference squared Q^2:

$$R(Q^2) = 1 + \lambda e^{-R_0^2 Q^2} \quad (1)$$

$$Q^2(k_1, k_2) \equiv -(k_1 - k_2)^2 = M_{12}^2 - 4M_\pi^2 \quad (2)$$

where M_{12} is the invariant mass of the pair, and λ and R_0 are parameters determined by a fit to the data. Although this is an empirical expression, it has been shown to describe $e^+ e^-$ collision data very well over a wide range of centre of mass energies [7-10].

In the limits of identical momenta, a completely chaotic source is expected to produce $R(Q^2 \to 0) = 2$. Since most experiments measure a less than maximum Bose-Einstein enhancement, the parameter λ was introduced [11] in front of the enhancement term to represent the strength of the observed effect. For a fully coherent pion source (pion laser), the Bose-Einstein enhancement term is expected to vanish ($\lambda = 0$), and claims have been made that λ is thus a measure of the degree of source coherence [12,13]. On the other hand, the parameter R, in the case of a fully chaotic source, corresponds to an average over the spatial and temporal source dimensions.

3. Experimental Procedure

The AMY detector (Fig. 1) consists of a tracking detector and shower counter inside a 3-T solenoid magnetic coil which is surrounded by a steel flux return yoke followed by a muon detection system. The charged-particle tracking detector consists of a 4-layer cylindrical array of drift tubes (inner tracking chamber, or ITC) and a 40-layer cylindrical drift chamber (central drift chamber, or CDC) with 25 axial layers of wires and 15 stereo layers. Charged particles are detected efficiently over the polar angle region $cos\theta <$ 0.87 with a momentum resolution $\Delta_{p_T}/p_T = 0.7\% \times [p_T$ (GeV/c)]. Radially outside of the CDC is a 15-radiation-length clyindrical electromagnetic calorimeter (barrel shower counter, or SHC) which serves as a photon detector. The detector fully covers the angular region $cos\theta < 0.73$. Selection of multihadron final states from $e^+ e^-$ annihilation was based on the charged particle momenta measured in the CDC and on the neutral-particle energy measured in SHC [14].

4. Two Body Bose-Einstein Correlation

4.1 Calculation of Correlation Function

For every event, all possible charged tracks were formed and Q^2, the negative of difference of the four-momenta squared, was calculated. Two histograms of the number of particle pairs were formed; one of like-signed pairs. These distributions are shown in Figures 2 and 3. The ratio of these two distributions was the correlation function, after making corrections for differences not related to the Bose symmetrization requirement of the like-signed pions. Such corrections are described below.

Differences between the like- and unlike-signed samples due to resonance decays, normalization, and detector effects were corrected using Monte-Carlo simulation techniques. This simulation was based on Lund 6.3 for 5-flavor parton production and the Lund

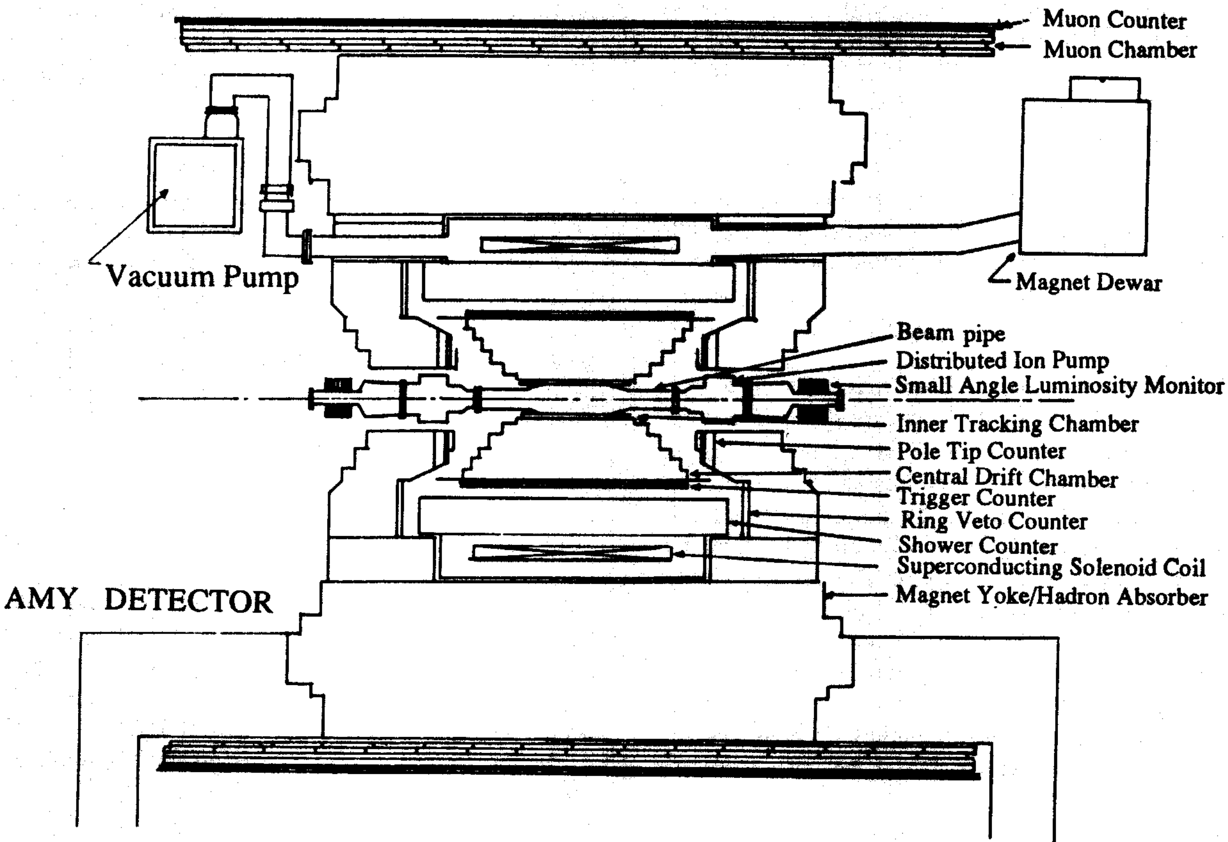

Figure 1. AMY detector

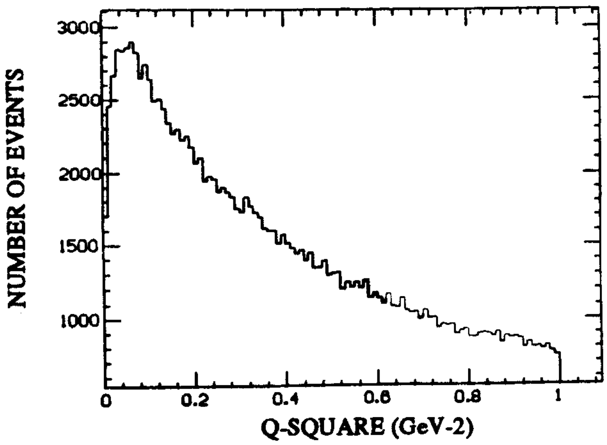

Figure 2. The distribution of like-signed particle pairs, for the AMY hadronic data sample, versus Q^2

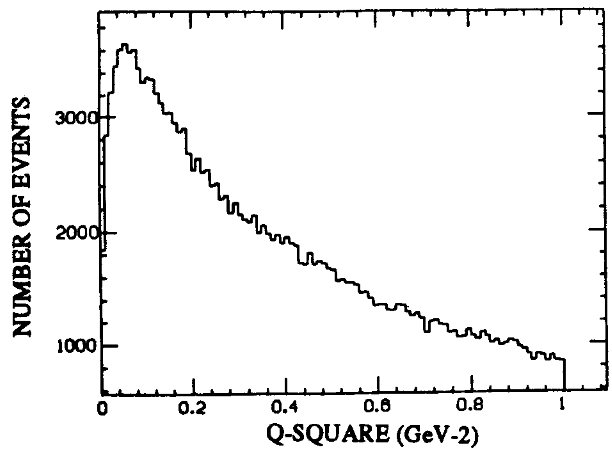

Figure 3. The distribution of unlike-signed particle pairs, for the AMY hadronic data sample, versus Q^2

string fragmentation model [15] for the hadronization process. It should be noted that the Monte Carlo does not contain Bose-Einstein correlations. From this simulated data, the Q^2 distribution of like- and unlike-signed pairs was calculated using the same cuts as for the real data. The measured correlation function was then divided by the ratio of these distributions.

Like-signed pairs of non-identical particles (π, K, p) do not contain Bose-Einstein correlations. The proportion of like-signed pairs that were not identical pions was determined using the Monte Carlo simulation, and was fit to a polynomial $f_\pi(Q^2)$. According to the Lund 6.3 Monte Carlo calculation, approximately 68% of all like-signed pairs were $\pi\pi$ pairs, with only a slight variation in Q^2.

Like-signed pions exert a mutually repulsive electromagnetic force, while unlike-signed pions feel an

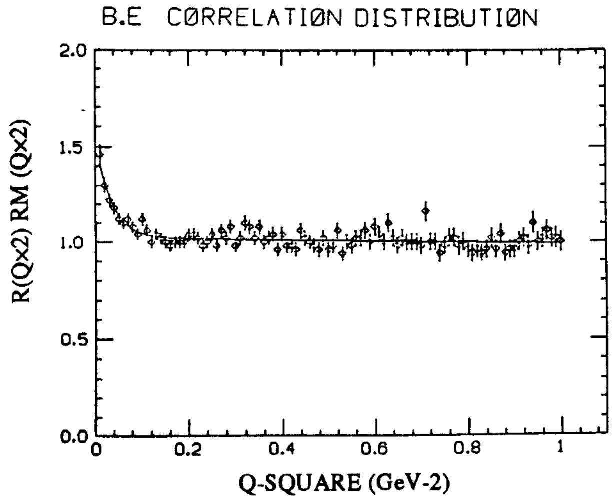

Figure 4. The like- to -unlike particle ratio normalized by the same ratio obtained from a Monte-Carlo, plotted as a function of Q^2. The solid curve represents a fit to the data

attractive force. This Coulomb interaction alters the distribution $R(Q^2)$ by an amount [16]:

$$R(Q^2) \rightarrow R(Q^2) \exp(2\pi\alpha M_\pi / Q) \quad (3)$$

where $2\pi\alpha M_\pi \approx 6.4$ MeV. This correlation is about 9.5% at a Q^2 value of 0.005 $(GeV)^2$.

4.2 Results

The ratio of like- to unlike-signed pairs as a function of Q^2, after applying all corrections, is shown in Figure 4. The spectrum was parameterized by:

$$R(Q^2) = N_0(1 + f_\pi(Q^2)\, \lambda e^{-R_0^2 Q^2})(1 + \gamma Q^2) \quad (4)$$

where N_0 is a normalization constant to take into account the different number of like- and unlike-signed pairs, λ and R_0 are the parameters of the Bose-Einstein correlation function, the term γ is used to take into account long-range correlations that exist (e.g. charge and energy conservation), and the function $f_\pi(Q^2) \approx 0.68$ as discussed previously. A fit to this spectrum yields parameter values of: $N_0 = 1.021 \pm 0.014$, $\lambda = 0.603 \pm 0.071$, $R_0 = 1.162 \pm 0.081$ fm, $\gamma = -0.041 \pm 0.025$ $(GeV/c)^{-2}$ with $\chi^2 = 92.5/96$; this is also shown in Figure 4. The inclusion of systematical uncertainty would result in a fluctuation of 4.5% to the above values for λ and R_0. The fact that N_0 and γ are approximately consistent with 1.0 and 0.0, respectively, indicates that the Monte Carlo corrections are reliable (without such corrections, values of $N_0 = 0.765$ and $\gamma = 0.148$ $(GeV)^{-2}$ were

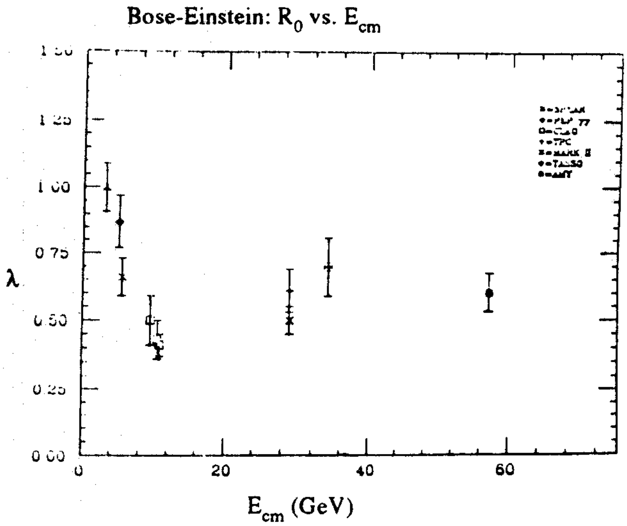

Figure 5. The Bose-Einstein parameter λ, versus center of mass energy, for a variety of experiments

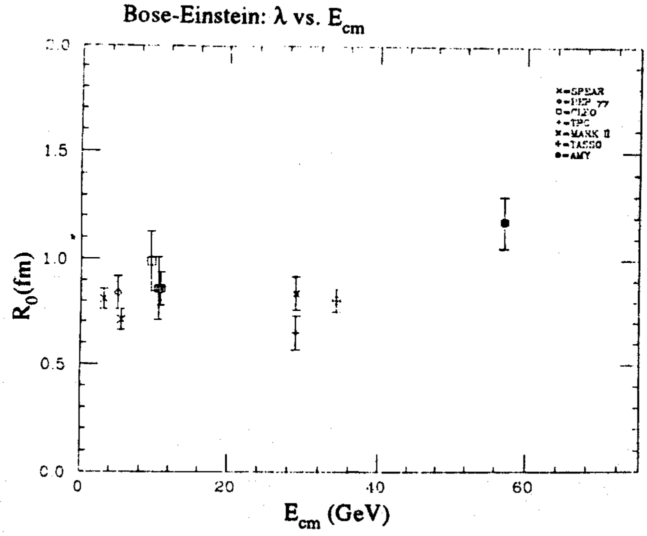

Figure 6. The Bose-Einstein parameter R_0, versus center of mass energy, for a variety of experiments

obtained).

4.3 Comparison to Previous Measurements

Bose-Einstein correlations in $\pi\pi$ production have been measured at a number of $e^+ e^-$ colliders. The results for the fit parameter λ versus centre of mass energy are shown in Figure 5 for various experiments. We have included the results obtained from AMY data with average centre of mass energy $\sqrt{s}$= 57 GeV. As the figure indicates, the AMY result for λ is, within experimental uncertainties, consistent with the lower energy data.

The results for R_0 are shown in Figure 6. In this case, the typical correlation distance of $R_0 \approx 0.8$ fm seems to be energy independent below the AMY energy range. The result from AMY, however, seems to indicate a possible increase in R_0 to above 1 fm. If the increase in the value of R_0 in the AMY energy range is a result of real physics, one possible explanation could be that the Z^0 contribution to the quark production process is altering the spatial dimensions of the hadronization process (however, the Z^0 lifetime is much too small to have any significant effect). Since the Z^0 contribution to the hadronic cross section goes from just a few percent at the lowest AMY energy to about 35% at the highest energy, it might be possible to see such an energy dependent effect within AMY energy range. Higher statistics may further clarify the situation.

5. Conclusion

Bose-Einstein correlations in $\pi\pi$ production have been measured in $e^+ e^-$ annihilations with the AMY detector at TRISTAN, using a hadronic event sample of 10200 events with $\sqrt{s}$ ranging from 50 to 61 *GeV*. Results show correlations with a strength of $\lambda = 0.61 \pm 0.07$ in agreement with lower energy results. The typical correlation size was determined to be $R_0 = 1.16 \pm 0.08$ fm, which is slightly larger than lower energy results have indicated. An increased data sample should help clarify any unexpected changes in hadronic production observed in the TRISTAN energy range.

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