

UR-1176

ER-13065-634



"BOSE-EINSTEIN CORRELATIONS IN PION
PRODUCTION AT TRISTAN"

By

R.C. Walker
University of Rochester
Department of Physics and Astronomy
Rochester, NY 14627

THE UNIVERSITY OF ROCHESTER
DEPARTMENT OF PHYSICS AND ASTRONOMY

ROCHESTER , NEW YORK

7/11/90

MASTER

Bo

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

BOSE-EINSTEIN CORRELATIONS IN PION PRODUCTION AT TRISTAN*

R.C. WALKER

National Laboratory for High Energy Physics (KEK)

Tsukuba, Ibaraki 305, Japan

University of Rochester

Rochester, NY 14627, USA

ABSTRACT

Measurements of Bose-Einstein correlations in the production of like-signed pion pairs have been made with the AMY detector at TRISTAN. An event sample of 3800 hadronic events with $\langle\sqrt{s}\rangle=57.2$ GeV was used. These measurements indicate a strength of the enhancement of $\lambda = 0.60 \pm 0.13 \pm 0.08$, with a typical correlation size of $R_0 = 1.18 \pm 0.17 \pm 0.10$ 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

Descriptions of the theoretical basis for Bose-Einstein correlations in the production of identical bosons (pions) can be found in a number of sources;¹⁻³ only a brief review will be given here. Given a chaotic (thermal) source of pions, and requiring that the pion wave function be symmetric under the exchange of identical bosons, the correlation function between two like-signed pions is related to the Fourier transform of the pion source distribution, $\hat{\rho}(k_1 - k_2)$, by:

$$C(k_1, k_2) = 1 + |\hat{\rho}(k_1 - k_2)|^2 \quad (1)$$

where k_1 and k_2 are the pion momentum. In order to extract this correlation function from data, it is customary to compare the distribution of like-signed pion pairs to unlike-signed pairs. This is due to the fact that the unlike-signed pair distribution contains much of the same physics as the like-signed distribution (*i.e.* phase space, momentum and angular distributions), but does not contain Bose-Einstein correlations. Differences exist, however, due to resonance decays and other phenomenon.

* Work supported in part by the U.S. Department of Energy.

The ratio of the distributions, $R \equiv N_{\text{like}}/N_{\text{unlike}}$, is frequently parameterized in terms of a Gaussian function of the four-momentum difference, Q :

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

$$Q^2(k_1, k_2) \equiv -(k_1 - k_2)^2 = M_{12}^2 - 4M_\pi^2 \quad (3)$$

where M_{12} is the invariant mass of the two pion system. The parameters λ and R_0 are related to the strength of the enhancement and the size of the source, respectively, and are determined by fits to the data. Although this expression is only empirical, it has been shown to describe e^+e^- annihilation data well over a wide range of energies⁴⁻⁷.

2. Experimental Data

2.1. AMY Detector

The AMY detector contains cylindrical tracking and shower detectors located inside a 3 T solenoidal magnet, and has been well documented elsewhere.⁸ Charged particles were detected using a 4-layer cylindrical array of tube-type drift cells followed by a 40-layer cylindrical drift chamber (CDC) with 25 axial and 15 small-angle stereo layers, covering the polar angle region $|\cos \theta| < 0.87$. From Bhabha scattering events, a resolution of $\delta p_T/p_T = 0.7\% p_T(\text{GeV})$ was determined. A cylindrical electromagnetic calorimeter, consisting of 20 layers of interspersed lead and resistive plastic proportional tubes, is situated radially outside of the tracking chamber, covering the angular region $|\cos \theta| < 0.73$. Muons were detected using four layers of drift cells and one layer of plastic scintillators, situated outside of the iron return yoke and covering the angular region $|\cos \theta| < 0.74$.

“Good” tracks in the CDC were determined by requiring a minimum number of wire hits, as well as vertex and polar-angle cuts. Multiple tracks caused by “curlers” (*i.e.* spiralling low momentum particles that reenter the CDC, resulting in two or more reconstructed tracks) were eliminated. The sample of events used were defined by the standard AMY hadronic event selection criteria.⁹ These criteria eliminated background events from beam-wall, beam-gas, $\tau^+\tau^-$, two-photon, and radiative Bhabha events; as well as guaranteeing no large energy leakage into the beam pipe. Backgrounds from these processes were estimated to be $< 2\%$.

Hadronic particle identification was not possible using the AMY detector. However, it was possible to eliminate tracks caused by electrons or muons using data from the Shower Counter and Muon Counter. It was required that there be at least five hadronic tracks, with at least two positively and two negatively charged, for the event to be included in this analysis.

2.2. Calculation of Correlation Function

For each event, all possible pairs of charged tracks were formed and Q^2 , the negative of the difference of the four-momenta squared, was calculated. Two histograms of the number of particle pairs were formed; one of like-signed pairs and one of unlike-signed pairs. These distributions are shown in Fig. 1. 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.

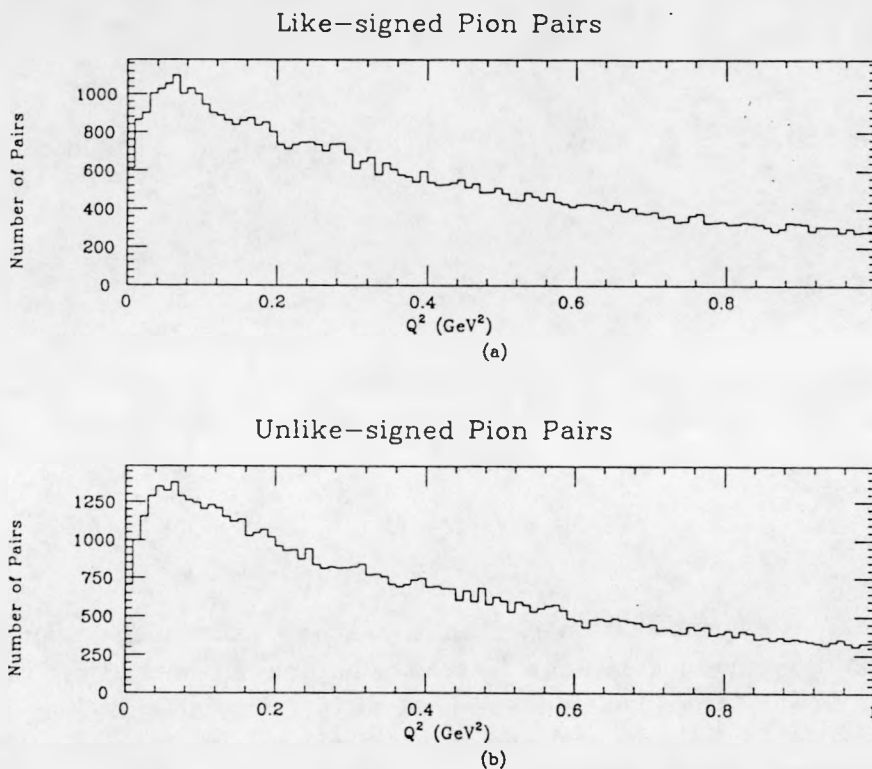


Figure 1 - The distributions of (a) like-signed particle pairs and (b) unlike-signed particle pairs, for the AMY hadronic data sample, versus Q^2 .

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 6.3¹⁰ for 5-flavor parton production and the Lund string fragmentation model¹¹ 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 distributions of like- and unlike-signed pairs were 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 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 attractive force. This Coulomb interaction alters the distribution $R(Q^2)$ by an amount¹²:

$$R(Q^2) \rightarrow R(Q^2) \exp(2\pi\alpha M_\pi/Q) \quad (4)$$

where $2\pi\alpha M_\pi \approx 6.4$ MeV. This correction is about 9.5% at a Q^2 value of 0.005 $(\text{GeV}/c)^2$.

3. Results

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

$$R(Q^2) = N_0(1 + f_\pi(Q^2)\lambda e^{-R_0^2 Q^2})(1 + \gamma Q^2) \quad (5)$$

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 involving γ is used to take into account long-range correlations that exist (*e.g.* charge and energy conservation), and the function $f_\pi(Q^2) \approx 0.68$ was discussed previously. A fit to this spectrum yields parameters of: $N_0 = 1.021 \pm 0.014$, $\lambda = 0.603 \pm 0.126$, $R_0 = 1.182 \pm 0.170$ fm, $\gamma = -0.041 \pm 0.025$ $(\text{GeV}/c)^{-2}$, with $\chi^2/\text{dof} = 92.5/96$; this is also shown in Fig. 2. The fact that N_0 and γ are approximately consistent with 1.0 and 0.0, respectively, indicates a good reliability of the Monte-Carlo corrections (without such corrections, values of $N_0 = 0.765$ and $\gamma = 0.148$ $(\text{GeV}/c)^{-2}$ were obtained).

A full study of the systematic uncertainties involved in this study, particularly those from the Monte-Carlo corrections, has not yet been carried out. An attempt has been made, however, to estimate some of the following sources of uncertainty:

Curlers. In order to eliminate multiple "curler" tracks that were caused by a single low-momentum particle following a helix through the CDC, some like-signed pion pairs at small relative angles may have been eliminated. This effect is limited to only the first Q^2 bin of the pair distributions, however, and good agreement was found

Bose-Einstein Correlations

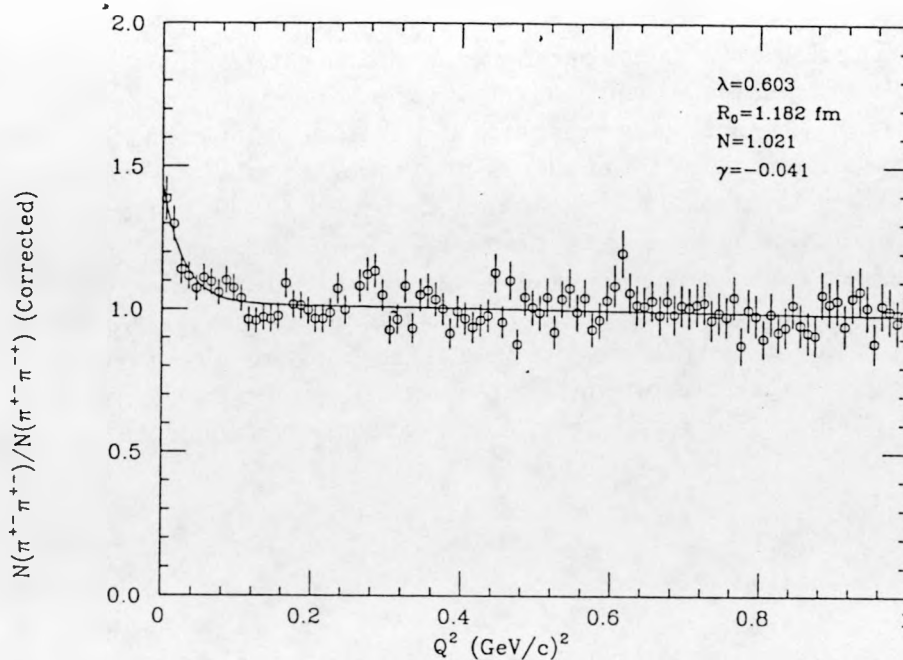


Figure 2 - Ratio of like- to unlike-signed particle pairs from the AMY data, after making all corrections.

between data and Monte-Carlo simulations. A 3% uncertainty has been assigned to this first bin to account for any errors, leading to a systematic uncertainty of ± 0.015 in λ and ± 0.025 fm in R_0 .

Resonance effects. A $\pm 30\%$ uncertainty in the $\pi^+\pi^-$ distribution resulting from η and η' decays has been included. This results in roughly a $\pm 2.5\%$ uncertainty in the ratio of like- to unlike-signed pairs in the region $Q^2 < 0.06$ (GeV/c) 2 . Based on this, an uncertainty in λ of ± 0.037 and a ± 0.066 fm uncertainty in R_0 has been included.

Monte-Carlo statistics. A systematic uncertainty equal to 0.42 times the statistical uncertainty was assigned to each of the fit parameters to account for the statistical precision of the Monte-Carlo (22,000 events).

Detector resolution. The effect of the resolution of the particle tracking was determined by simulating the Bose-Einstein enhancement, with parameters $\lambda = 0.60$ and $R_0 = 1.18$ fm, in the Monte Carlo. After simulating detector resolution effects and fitting the resulting correlation function, extracted values of λ and R_0 were 0.56 and 1.18 fm, respectively. A systematic error of 0.04 was thus assigned to λ .

Further studies of the systematic uncertainties is currently underway.

4. Comparison to Previous Measurements

The results for the fit parameter λ versus center-of-mass energy are shown in Figure 3(a) for this experiment, as well as various lower energy e^+e^- experiments.⁴⁻⁷ Also shown are the thresholds for charm and bottom production. The results show λ near a maximum value of 1.0 at charm-production threshold. The value decreases above the charm threshold, and is further decreased as the bottom threshold is crossed. This reduction is thought to be caused by the fact that a significant number of pions are produced not as a result of the initial hadronization, but rather as the decay products from the heavy quarks. Since the quarks travel a significant distance (compared to $R_0 \approx 1$ fm) before decaying, these pions are effectively "uncorrelated" within the experimental resolution of the detectors. However, this phenomenon is not well understood.^{3,7} The results from AMY are consistent with other results above bottom threshold.

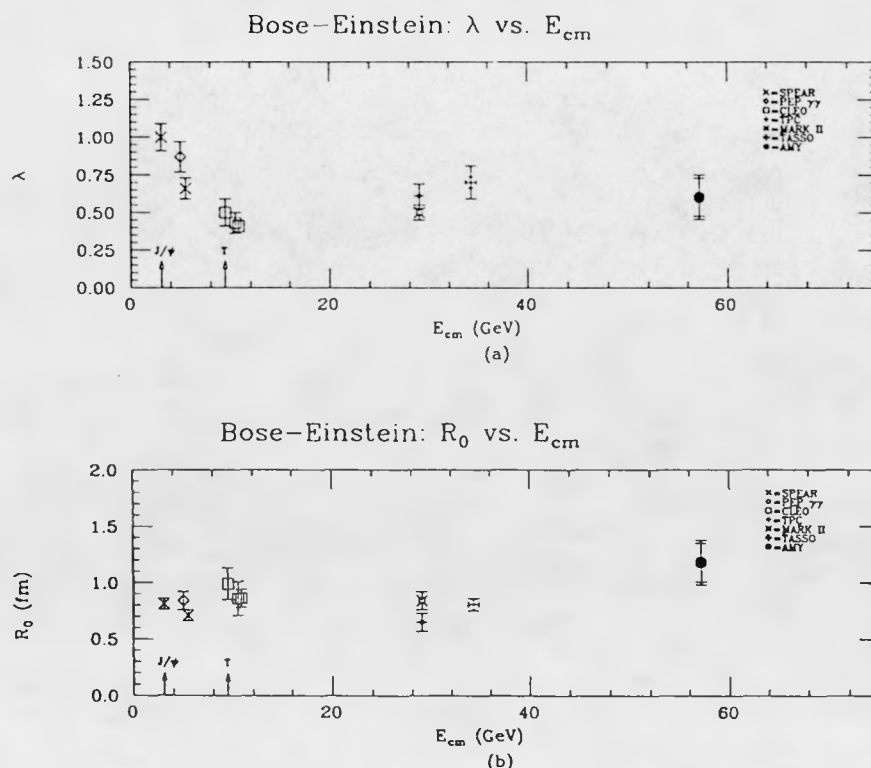


Figure 3 - (a) The Bose-Einstein parameter λ , shown versus center-of-mass energy, for a variety of experiments. (b) The Bose-Einstein parameter R_0 .

In Figure 3(b) the results for R_0 are shown. In this case, the typical correlation distance of $R_0 \approx 0.8$ fm is energy independent below the AMY energy range. The results from AMY, however, indicate a possible increase in R_0 to above 1 fm; however, the discrepancy is only 2.2 standard deviations. Increased statistics, which will be achieved over the next three years of TRISTAN running, along with improved tracking with the AMY 1.5 detector, should make it possible to determine whether this discrepancy is real, or only a statistical fluctuation.

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 3800 events with $\langle\sqrt{s}\rangle=57.2$ GeV. Results show correlations with a strength of $\lambda = 0.60 \pm 0.13 \pm 0.08$, in agreement with lower energy results. The typical correlation size was determined to be $R_0 = 1.18 \pm 0.17 \pm 0.10$ fm, which is slightly larger than lower energy results have indicated. An increased data sample presently being taken with the AMY 1.5 detector at TRISTAN at $\sqrt{s} = 58$ GeV should help clarify if any changes in hadronic production in the TRISTAN energy range are being observed.

References

1. G. Goldhaber, *et al.*, *Phys. Rev.* **120**, 300 (1960).
2. A. Giovannini and G. Veneziano, *Nucl. Phys.* **B130**, 61 (1977).
3. I. Juricic, Ph.D. thesis, Lawrence Berkeley Laboratory, (1987).
4. TPC Collaboration, H. Aihara, *et al.*, *Phys. Rev.* **D31**, 996 (1985).
5. CLEO Collaboration, P. Avery, *et al.*, *Phys. Rev.* **D32**, 2294 (1985).
6. TASSO Collaboration, M. Althoff, *et al.*, *Z. Phys.* **C30**, 355 (1986).
7. Mark II Collaboration, I. Juricic, *et al.*, *Phys. Rev.* **D39**, 1 (1989).
8. AMY Collaboration, T. Kumita, *et al.*, submitted to *Phys. Rev.*
9. T. Mori, Ph.D. Thesis, University of Rochester, UR-1104, (1988).
10. T. Sjostrand, *Com. Phys. Comm.* **43**, 367 (1987).
11. B. Andersson, *et al.*, *Phys. Rep.* **97**, 33 (1983).
12. M. Gyulassy, *et al.*, *Phys. Rev.* **C20**, 2267 (1979).