UCRL 8814

UNIVERSITY OF CALIFORNIA

Ernest O. Lawrence Radiation Laboratory

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 5545

BERKELEY, CALIFORNIA

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal 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 its 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, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

For pub. Phys. Rev. Letters UCRL-8814

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

PION-PION CORRELATIONS IN ANTIPROTON ANNIHILATION EVENTS

Gerson Goldhaber, William B. Fowler, Sulamith Goldhaber,
T. F. Hoang, Theodore E. Kalogeropoulos, and Wilson M. Powell

July 14, 1959

Printed for the U. S. Atomic Energy Commission

PION-PION CORRELATIONS IN ANTIPROTON ANNIHILATION EVENTS*

Gerson Goldhaber, William B. Fowler, Sulamith Goldhaber, T. F. Hoang, Theodore E. Kalogeropoulos, and Wilson M. Powell

Lawrence Radiation Laboratory and Department of Physics
University of California
Berkeley, California

July 14, 1959

We have observed angular-correlation effects between pions emitted from antiproton annihilation events. This experiment was carried out with a separated antiproton beam[1] of momentum $p_{\bar{p}} = 1.05$ Bev/c. A total of 2500 annihilation events were observed in 20,000 pictures taken with the Lawrence Radiation Laboratory 30-in. propane bubble chamber.

Pion pairs formed by the charged pions emitted in an antiproton-annihilation event can be considered in two groups: viz., like pairs (in the isotopic-spin state I = 2) and unlike pairs (in the isotopic-spin states I = 0, 1, or 2). We searched for correlation effects in these separate groups. Our results show that the distribution of the angles between pions of like charges is strikingly different from the distribution of the angles between pions of unlike charges. The angles between pion pairs was computed in the center of mass of the antinucleon-nucleon system.[2] The results shown in Fig. 1 were obtained from the analysis of the "hydrogenlike" events in which four and six charged pions, respectively, are emitted. We define as "hydrogenlike" those events giving rise to an equal number of positive and negative pions. Events showing visible evaporation prongs are excluded from this sample. The curves shown in Fig. 1 were calculated on the basis of the statistical model, expressed in the Lorentz-invariant phase-space[3] (LIPS) form, for pion production from a

---

*Work done under the auspices of the U. S. Atomic Energy Commission.

nucleon-antinucleon annihilation. This model imposes energy and momentum conservation, but no other constraints. The distribution of the pion-pair angles θ_{12} for an annihilation into n pions of mass μ is[4]

$$\phi_n(\cos\theta_{12}) = \iint p_1 p_2 F_{n-2}(W''^2)\, d\omega_1\, d\omega_2,$$

with integration limits from $\omega_1 \geq \mu$, $\omega_2 \geq \mu$ to max values given by $W''^2 = (n-2)^2 \mu^2$. Here we define

$$W''^2 = (W - \omega_1 - \omega_2)^2 - (\vec{p}_1 + \vec{p}_2)^2 ;$$

$F_{n-2}(W''^2)$ is the Lorentz invariant phase space for (n - 2) pions, W is the total energy in the center of mass of the antinucleon-nucleon system, and we have

$$\cos\theta_{12} = \frac{\vec{p}_1 \cdot \vec{p}_2}{|p_1|\ |p_2|} .$$

To compare with the experimental distributions for events with $n_\pm$ charged pions, averages over ϕ_n values with $n \geq n_\pm$ are required. This takes into account the presence of additional neutral pions in the annihilation. We have used the frequency distribution of the pion multiplicity in annihilation events, as reported elsewhere,[5] for computing these averages.

In Table I we have expressed the distribution of pair angles in terms of the ratio, γ, of the number of pion-pair angles greater than 90° to the number smaller than 90°. As can be seen from Fig. 1 (c) and (f), the pion-pair distribution of like and unlike pions combined agree very well with the LIPS model.[6] The distribution of angles between like pions [Fig. 1(a) and (d)] deviates distinctly from the LIPS model. The γ_{like} values for $4\pi^\pm$ and $6\pi^\pm$ differ from γ_{LIPS} by 5 and 3.4 standard deviations, respectively, in the direction of greater isotropy. The distribution of pion-pair angles for unlike pions appears to be slightly more asymmetric than the LIPS model predicts.

Table I

The ratio γ for like and unlike pion pairs and for the Lorentz-invariant phase-space (LIPS) model.[a]

	Like pions		Unlike pions		All pions combined		Statistical model
$N_{\pi^\pm}$	No. of pairs	γ	No. of pairs	γ	No. of pairs	γ	γ
4	702	1.23±0.11	1404	2.06±0.12	2106	1.72±0.08	1.74
6	214	1.06±0.15	318	1.91±0.23	532	1.50±0.13	1.60

[a]The ratio γ is the number of pion-pair angles greater than 90° compared to those smaller than 90°. The errors quoted are the standard deviations based on the number of pairs observed.

In this case, the values of γ_{unlike} are 2 and 1.5 standard deviations, respectively, removed from the value given by the LIPS model.

We have also computed the invariant quantity

$$Q_{12}^2 = (\omega_1 + \omega_2)^2 - (\vec{p}_1 + \vec{p}_2)^2$$

for each pion pair. Here Q is the total energy in the center of mass of the pion-pion system. These distributions are given in Fig. 2. Within statistical limits no significant difference between the Q^2 distribution of like and unlike pion pairs has been observed. Curves shown in Fig. 2 were also computed on the basis of the LIPS statistical model. The experimental Q^2 distributions show no marked deviation from the calculated curves.

In view of the remarkable agreement of the combined data with the LIPS model, we consider this model to be a good description of the over-all physical situation. We ascribe the deviations observed in the like and unlike pion pairs to the presence of additional pion-pion correlations.

It should be noted that in order to retain the over-all agreement with the LIPS model, a correlation effect present in either of the two distributions must reflect on the other distribution. The effect we have observed clearly indicates the need for a refinement of the LIPS model.

Work is in progress to investigate modifications of the LIPS model by means of correlation functions which may account for the observed pion-pion correlations.[7] These correlation functions involve the radius R of the interaction volume as a parameter, and may enable one to determine its value. The role of such correlations will be to effectively enhance specific states. In this connection the recently suggested resonance of the 2π system with $J = 1$, $I = 1$ may be of particular interest.[8]

We would like to thank Howard S. White for his valuable help in the data analysis.

Footnotes

1. Alvarez, Eberhard, Good, Graziano, Ticho, and Wojcicki, Phys. Rev. Lett. 2, 215 (1959). We are greatly indebted to Drs. Eberhard, Good, and Ticho for help in tuning their beam from K^- mesons to antiprotons.
2. In the center-of-mass transformation, we considered the target nucleon to be at rest.
3. P. P. Srivastava and G. Sudarshan, Phys. Rev. 110, 765 (1958).
4. Theodore E. Kalogeropoulos, A Study of the Antiproton Annihilation Process in Complex Nuclei (Thesis), UCRL-8677, March 6, 1959.
5. Chamberlain, Goldhaber, Jauneau, Kalogeropoulos, Segrè, and Silberberg, Phys. Rev. 113, 1615 (1959).
6. Similar results were observed earlier in an emulsion experiment (See references 4 and 5).
7. Dr. J. V. Lepore and also Dr. A. Pais, Lawrence Radiation Laboratory (private communications).
8. W. R. Frazer and J. R. Fulco, Phys. Rev. Lett. 2, 365 (1959).

Figure Legends

Fig. 1. Distribution of angles between pion pairs as a function of $\cos\theta_{12}$. The curves correspond to calculations on the Lorentz-invariant phase-space (LIPS) model. The deviations of the experimental distribution from the LIPS model are discussed in the text.

Fig. 2. The distribution of Q^2, the square of the total energy in the center of mass of the pion-pion system in units of μ^2.

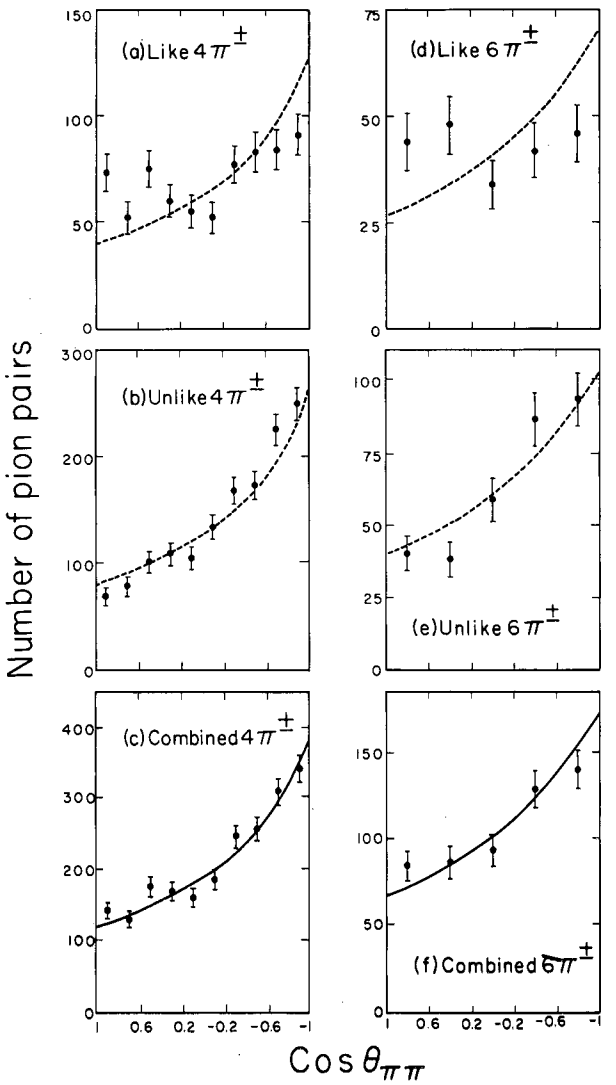
(a) Like 4 π±
(b) Unlike 4 π±
(c) Combined 4 π±
(d) Like 6 π±
(e) Unlike 6 π±
(f) Combined 6 π±
Number of pion pairs
Cos θππ
MU-17669

Fig. 1

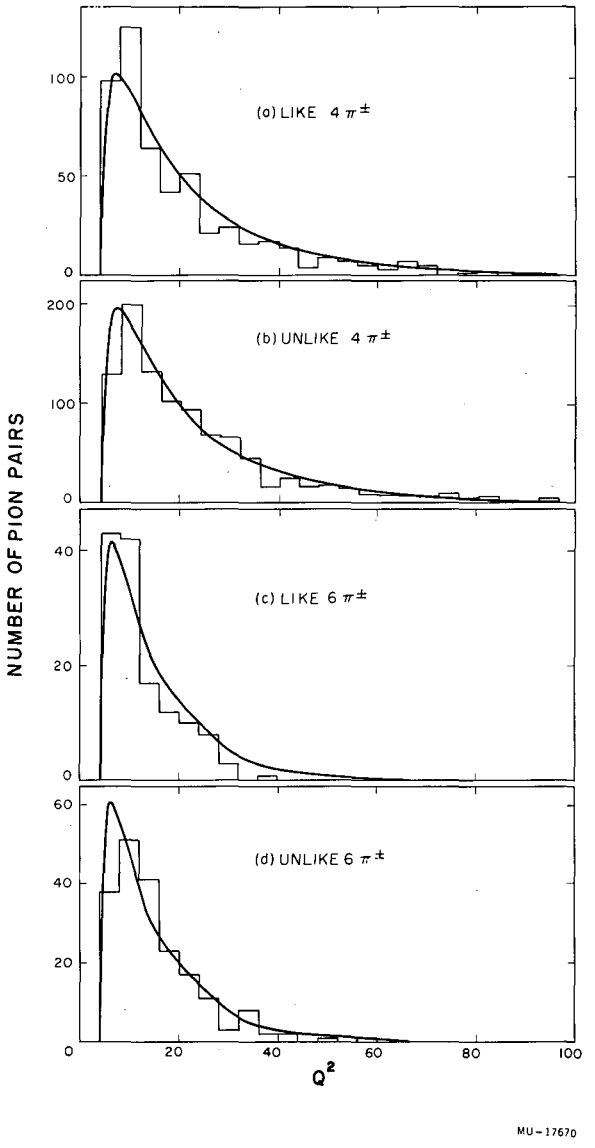
NUMBER OF PION PAIRS
(a) LIKE 4 $\pi^{\pm}$
(b) UNLIKE 4 $\pi^{\pm}$
(c) LIKE 6 $\pi^{\pm}$
(d) UNLIKE 6 $\pi^{\pm}$
Q^2
MU-17670

Fig. 2