fore the region examined was $0° < \phi < 180°$. The angle ϕ was defined as follows:

$$\cos\phi = (1^- \times 1^+)(2^- \times 2^+),$$

The result, $\langle C \rangle = -0.77 \pm 0.53$, is inconclusive due to the large error.

V. CONCLUSION

We have presented here measurements on the decay $\pi^0 \rightarrow 2e^+ + 2e^-$ which have been interpreted to yield a measurement of the pion parity. The analysis depends on (a) invariance arguments due to Yang and originally presented for the two-photon decay of the π^0, and (b) on the validity of electrodynamics as applied to this problem. The validity of the invariance arguments need hardly be discussed; if they are not valid, then the parity is also without meaning. The electrodynamical theory is by now extensively verified. Nevertheless, we have presented here several additional experimental checks of the theory; namely the predictions of the theory for those features of the internal conversion of π^0 decay which are not directly used in the parity determination. These checks are:

(1) The angular and energy distributions for the leptons in the decay $\pi^0 \rightarrow \gamma + e^+ + e^-$;

(2) The angular and energy distributions for the individual pairs in the decay $\pi^0 \rightarrow 2e^+ + 2e^-$;

(3) The distribution in $\alpha(x_1y_1, x_2y_2)$ for the decay $\pi^0 \rightarrow 2e^+ + 2e^-$;

(4) The absolute rates for the two internal conversion processes.

In all cases, agreement with the theory is good and we have a high level of confidence in the theory for predicted correlations.

On the basis of 112 analyzable events out of a total of 206, we find then a correlation which agrees very well (0.25 standard deviations) in the case of a pseudoscalar pion, and disagrees with the correlations predicted for the scalar case by 3.6 standard deviations. This reinforces the long-standing result from the π^- capture in deuterium.[1]

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Particle Production at Large Angles by 30- and 33-Bev Protons Incident on Aluminum and Beryllium*

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A mass analysis has been made of the relatively low momentum particles emitted from Al and Be targets when struck by 30- and 33-Bev protons. Measurements were made at 90°, 45°, and $13\frac{1}{4}°$ relative to the direction of the Brookhaven AGS proton beam. Magnetic deflection and time-of-flight technique were used to determine the mass of the particles.

As part of the beam survey program at the Brookhaven alternating gradient synchrotron (AGS) a mass analysis has been made of the relatively low momentum particles emitted from aluminum and beryllium targets when struck by 30- and 33-Bev protons. These measurements were made at $13\frac{1}{4}°$, 45°, and 90° relative to the direction of the incident proton beam. Similar work has been done at CERN[1–3] and Brookhaven[4] at relatively small angles ($\theta \leq 20°$).

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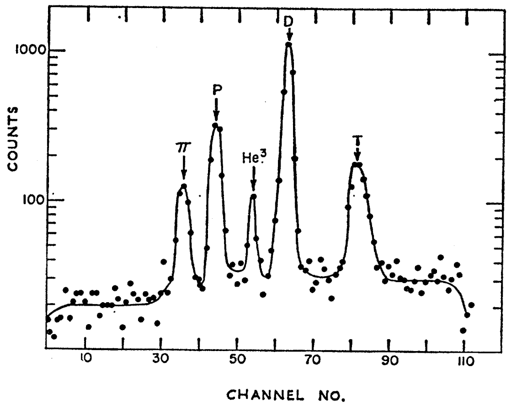

FIG. 1. Time-of-flight spectrum for 1-Bev/c positive particles. One nanosecond corresponds to 1.9 channels. The helium-3 particle momentum is 2 Bev/c because of its double charge. As explained in the text the protons and π mesons were purposely detected with low efficiency in this particular run.

The mass of the particles was determined from momentum and velocity, using magnetic deflection and time-of-flight technique. The general method differs only in detail from that used by Cocconi *et al.*[1] at CERN. Two scintillation counters S_1 and S_2 determined the distance over which the time of flight was measured. This distance was 95 ft at 13° and 12 ft at 45° and 90°. A 256-channel pulse-height analyzer, preceded by a time-to-amplitude converter, was used to record the time difference between pulses in S_1 and S_2. Figure 1 shows a sample time-of-flight spectrum. In this particular case the protons and π mesons were purposely detected with low efficiency (using dE/dx) in order to decrease the background and thereby enhance the less abundant particles. This resulted in a broadening of the proton and π-meson peaks due to poorer time resolution.

The 90° and 45° data were taken when the conditions of machine operation were identical to those described by Baker *et al.*[4] Most of the 13° data were taken with aluminum and beryllium targets alternately flipped into the beam from pulse to pulse and with the AGS operated at 33 Bev.

Figures 2–4 show the momentum distributions of particles produced at the target. Corrections have been made for multiple Coulomb scattering, diffraction scattering, nuclear absorption, and decay when appropriate. The dashed portions of the curves indicate regions where the corrections due to multiple scattering exceed 15%. At 45° and 90° the flight distance was neither sufficiently large nor the momentum resolution good enough to distinguish K mesons. At 45° the intensity of antiprotons relative to that of π^- mesons was less than 10^{-4}. A systematic error as high as 25% may affect the number of circulating protons.[4] It is believed that the efficiency for both aluminum and beryllium targets is about 50%.[4,5]

The 13° results presented here are in good general agreement with those of Baker *et al.*[4] and those obtained at CERN by Cocconi *et al.*[1] at 25-Bev proton energy and 15.9°. At small angles (in this case 13°) it is also observed that the pion intensity from the beryllium target is about 30% larger than from the aluminum target. The double targeting arrangement used should normalize out errors due to relative monitoring, beam normalization, or fluctuations in target efficiency. At 45° the deuteron intensity from Al exceeds that from Be by a factor ~2. This ratio falls to ~1.3 at 13°.

From the 90° data the following qualitative deductions may be made: (1) Assuming a primary proton-proton collision the intensities at 90° may be compared directly with those measured at forward angles and high momentum since there must be forward-backward symmetry in the center-of-mass system. To make this comparison the 90° intensity, $d^2N/dpd\Omega$, as well as the

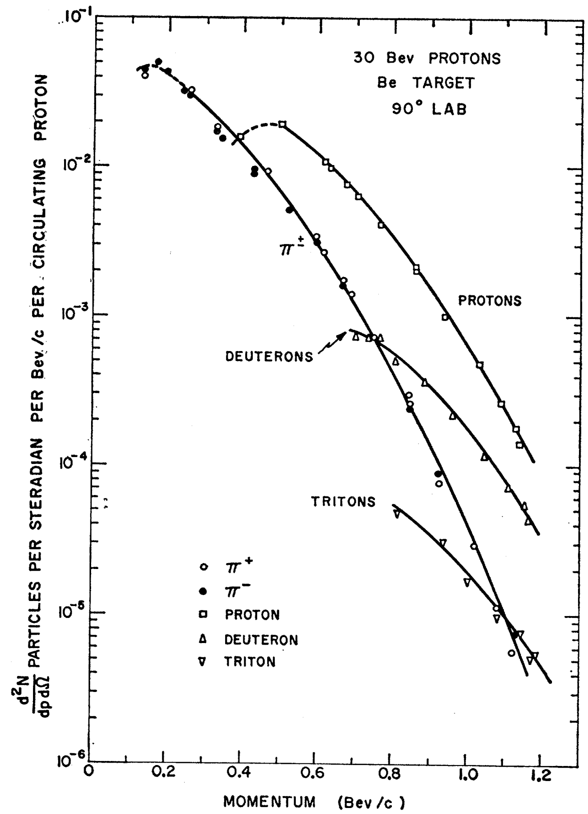

FIG. 2. Momentum spectrum of particles emitted at 90° from a beryllium target struck by 30-Bev protons. The ordinate is the number of particles produced at the target per steradian per Bev/c per circulating proton. The dashed portions of the curves indicate regions where the corrections due to multiple scattering exceed 15%. At the time these data were taken no effort was made to detect He^3.

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momentum p and the angle $\theta=90°$ must be transformed to the c.m. system, then reflected in the plane perpendicular to the velocity of the c.m., and transformed back to the laboratory. For 400-Mev/c π mesons the transformed momentum and angle are 14.5 Bev/c and 1.6°, respectively. The transformed intensity is 38 times the 90° intensity, whereas the measured intensity,[4] extrapolated to 1.6, is only $\sim$3 times the 90° intensity. It is therefore apparent that most of the π mesons observed at 90° must have originated in secondary or cascade processes if it is assumed that the high-momentum pions produced in the forward direction come from primary proton-proton collisions. (2) The deuterons observed at 90° are of particular interest because of (a) their relatively large abundance and (b) the fact that they are in a momentum range where the "pick-up" process has been explored both theoretically[6] and experimentally.[7,8] In view of these previous results it appears that an analysis of the deuterons in terms of a "pick-up" process

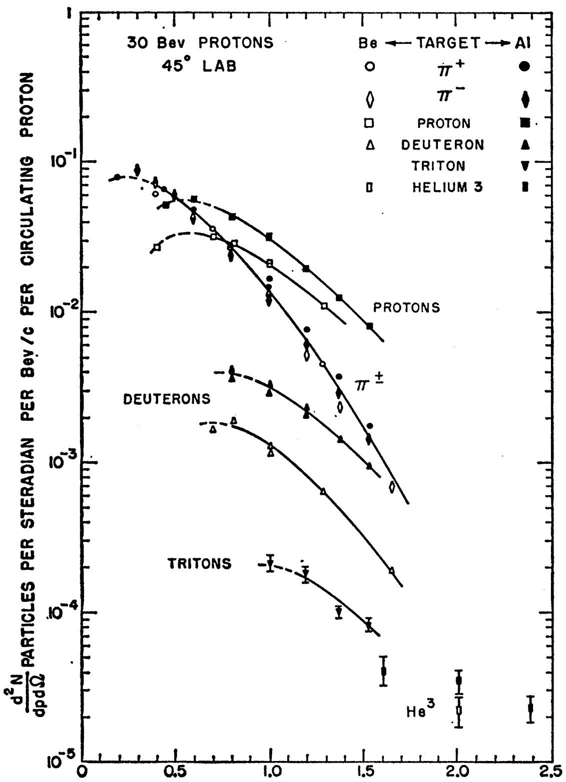

FIG. 3. Momentum spectra of particles emitted at 45° from aluminum and beryllium targets when struck by 30-Bev protons. Tritons from Be were not measured. For general remarks refer to Fig. 2 caption.

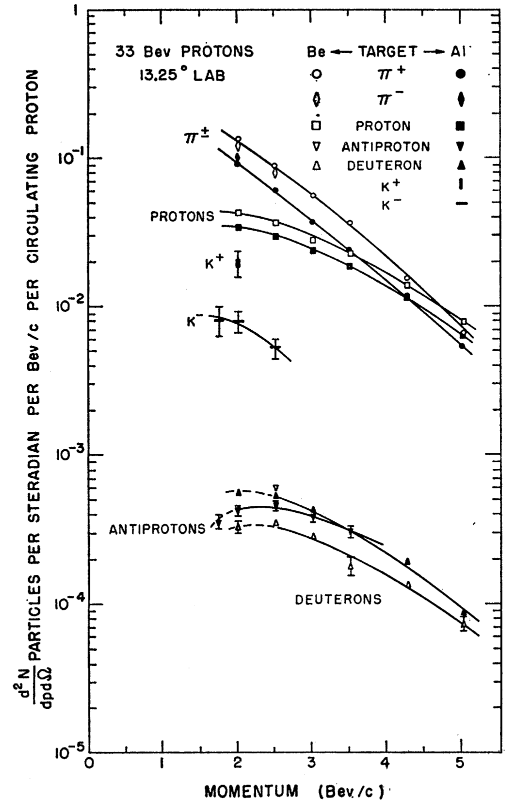

FIG. 4. Momentum spectra of particles emitted at $13\frac{1}{4}°$ from aluminum and beryllium targets when struck by 33-Bev protons. The $K^\pm$ mesons and antiprotons from Al were measured at 30-Bev incident proton energy. For general remarks refer to Fig. 2 caption.

may be of interest. Their abundance can be roughly estimated using the following crude model. The protons observed at 90° are considered as originating in a cascade process involving first a collision of the incident 30-Bev proton with one or perhaps several nucleons of the target nucleus. The protons emitted around 90° traverse part of the residual nucleus undergoing additional scattering or "pick-up" processes. Measurements at 430 Mev/c[7] showed the "pick-up" cross section to be approximately 10% geometric in light nuclei with little transfer of energy. One might expect, therefore, the proton intensity relative to that of the deuteron to be about 10 at the same energy. The observed ratio in this proton momentum range is 20. This difference might be due to the partial transparency of the residual nucleus. Indeed as one goes to larger nuclei (Al) the number of deuterons relative to the protons increases by a factor 1.5-2.

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