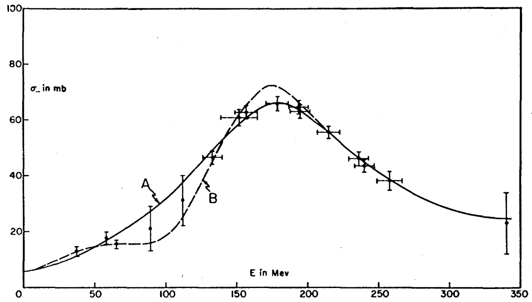

FIG. 1. Total cross section for negative pions. The experimental results are given together with the probable errors. Curve A is similar to that of reference 3. Curve B is more consistent with the dispersion relations.

In Fig. 1 are presented two curves of the cross section *versus* energy which correspond adequately to the data. Curve A is similar to the curve used by Anderson, Davidon, and Kruse.[3] Curve B begins to rise more rapidly near 100 Mev, which may be attributed to the influence of some of the p waves. It should be noted that the difference between curves A and B is permitted chiefly by the data near 100 Mev, which has a large experimental error. Curve B also has a somewhat larger maximum than Curve A. The important effect is the substantially greater slope of B over A in the region near 150 Mev, where the previous analysis had achieved a very poor fit. A similar variation is possible in the curve of the positive-pion total cross section, but the dispersion relation for forward scattering of negative pions is not sensitive to this. For higher energies than 350 Mev we use the values indicated by reference 1.

In Fig. 2 the forward scattering resulting from Curve A is plotted for $f^2=0.04$ and $f^2=0.08$. The result is similar to that of reference 1. We have added the experimental value of the forward scattering at 307 Mev, which is now available.[4]

In Fig. 3 the forward scattering resulting from Curve B is plotted for $f^2=0.07$ and $f^2=0.08$. Both of these

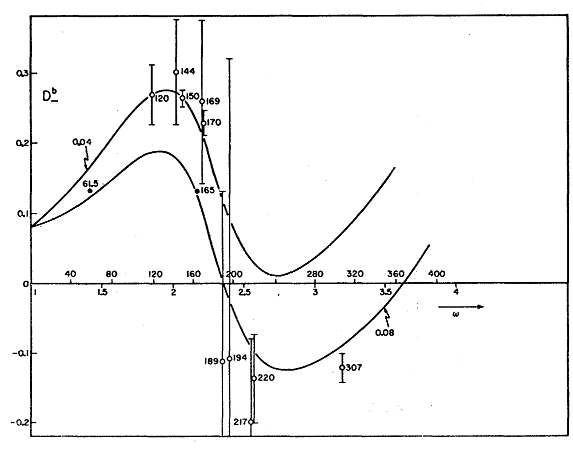

FIG. 2. The forward scattering amplitude for negative pions. The theoretical curves are calculated from Curve A of Fig. 1. The experimental values are as given in reference 1, except that for 307 Mev.[4] In the latter case only the statistical error is included.

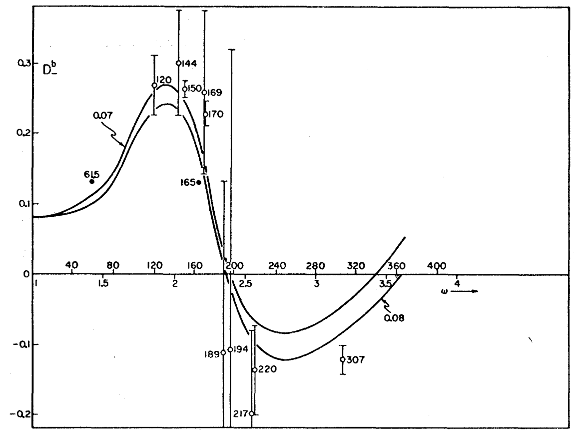

FIG. 3. The forward scattering amplitude for negative pions. The theoretical curves are calculated from Curve B of Fig. 1. The experimental values are the same as in Fig. 2.

values of f^2 are consistent with the positive pion scattering and with photoproduction.[5] For both values the fit is much better than obtained in reference 1. For $f^2=0.07$, only the 170-Mev forward scattering amplitude is in serious disagreement. The result could be further improved by minor modifications in the total cross-section curve employed.

We conclude that Curve B, or some similar curve through the total cross-section data, does not significantly contradict the dispersion relations or charge independence. It should be possible to distinguish experimentally between Curves A and B by re-examining the 100-Mev region.

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† Now with the Department of Mathematics, McGill University, Montreal, Quebec, Canada.

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Demonstration of Parity Nonconservation in Hyperon Decay*†

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AS is well known, the question of parity conservation in particle decays was raised first by the proper-

TABLE I. Exposure particulars.

Incident π^- beam kin. energy (Mev)	Chamber size and filling	Mag. field (kgauss)	Exposing group	Analyzing group
910	12 in. diam×8 in., C_3H_8	13.4	C.U.-BNL	Bologna
950	12 in. diam×6 in., H_2	13.4	C.U.-BNL	C.U.-BNL
1100	12×5×5 in., C_3H_8	···	Michigan	Michigan
1200	12 in. diam×8 in., C_3H_8	13.4	C.U.-BNL	Pisa
1300	12 in. diam×8 in., C_3H_8	13.4	C.U.-BNL	C.U.-BNL

ties of 2π and 3π K^+ decay. Actual proof of nonconservation of parity was then obtained for nuclear β-decay,[1] and $\pi\rightarrow\mu$ and $\mu\rightarrow e$ decay,[2] following the suggestions of Lee and Yang[3] to study these processes. The main feature of the experimental discoveries were very quickly interpreted in terms of theories in which the nonconservation of parity can be regarded as an intrinsic property of the neutrino.[4] It is therefore highly useful to study the question of nonconservation of parity in processes not involving neutrinos. We report here a clear-cut answer for the case of Λ^0 decay into pion and proton.

Following the suggestions of Lee *et al.*,[5] we have studied the correlation between production and decay angles in the two processes:

$$\pi_i^-+p\rightarrow\Lambda^0+\theta^0,\quad \Lambda^0\rightarrow\pi_f^-+p; \tag{1}$$

$$\pi_i^-+p\rightarrow\Sigma^-+K^+,\ \Sigma^-\rightarrow\pi_f^-+n. \tag{2}$$

The first step in the reaction serves to prepare a state of hyperons, in general polarized. The polarization axis is the normal to the production plane, $\mathbf{p}_{\pi\ \mathrm{in.}}\times\mathbf{p}_Y$. The magnitude of the polarization, P, is a function of the production angle, ω. $P=P(\omega)$ is at present not known experimentally. $P=\pm1$ represents complete polarization.

If parity is not conserved in the subsequent hyperon decay, this will in general result in an anisotropy in the distribution in the decay angle θ of the pion relative to the polarization axis, in the hyperon center-of-mass system. The form of the distribution is $[1+P(\omega)\alpha\cos\theta]$, where $\alpha(|\alpha|\leq1)$ is the anisotropy coefficient for completely polarized hyperons. Demonstration of a nonvanishing α is proof of parity nonconservation in the decay.

TABLE II. Tabulation of results on anisotropy in the angle between decay pion and production plane normal for process (1) (Λ^0).

Kin. energy Mev	No. of events	Up/down	$\Sigma_i\cos\theta_i$	$\bar{P}\alpha$
910	55	38.5/16.5	+12.12	+0.66±0.23
950	57	35/22	+ 8.50	+0.45±0.23
1100	42	28/14	+ 8.13	+0.58±0.27
1200	46	21/25	− 1.19	−0.08±0.26
1300	63	35.5/27.5	+ 7.57	+0.36±0.22
Totals	263	158/105	+35.13	+0.40±0.11

TABLE III. Tabulation of results on anisotropy in the angle between decay pion and production plane normal for process (2) (Σ^-).

Kin. energy Mev	No. of events	Up/down	$\Sigma_i\cos\theta_i$	$\bar{P}\alpha$
950	26	11/15	−1.53	−0.21±0.35
1100	44	25/19	1.52	+0.10±0.26
1200	32	16/16	−1.98	−0.19±0.31
1300	63	30/33	−1.84	−0.09±0.22
Totals	165	82/83	−3.87	−0.07±0.14

We have studied processes (1) and (2) in bubble chambers exposed to high-energy pions at the Brookhaven National Laboratory Cosmotron. Particulars of the exposures are given in Table I.

The production events have been carefully measured and analyzed, especially in the propane exposures, to exclude carbon events and events in which the Λ^0 is the product of a primary Σ^0. The combined sample for reaction (1) should contain no more than 8% contamination of carbon events, and no more than 5% Σ^0 events. The sample for reaction (2) is less than 3% contaminated.

Results on the anisotropy are summarized in Tables II and III, and the θ distributions for the combined energies are shown in Figs. 1 and 2. The anisotropy coefficients $P\alpha$ are calculated from the individually observed angles:

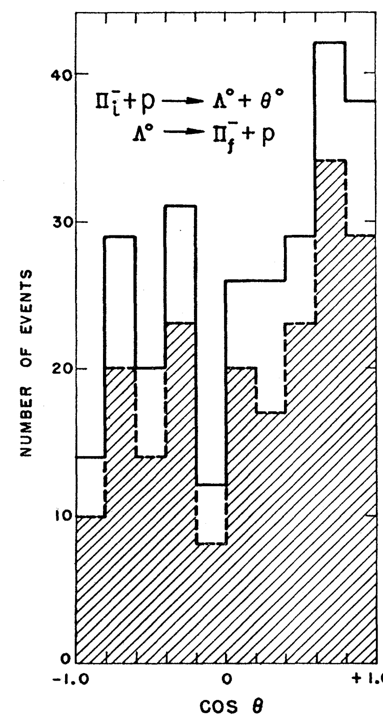

FIG. 1. Distribution in cosθ for process (1). The shaded area represents events for production angles in the center-of-mass range 30°–150°.

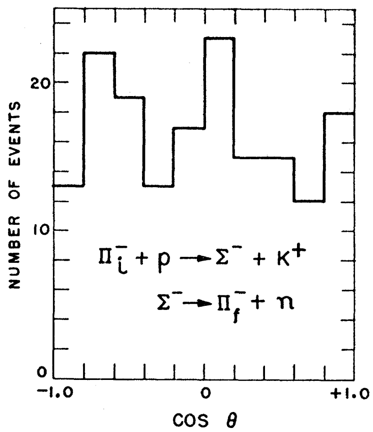

FIG. 2. Distribution in $\cos\theta$ for process (2).

$$\bar{P}\alpha=\frac{3}{N}\sum_{i=1}^{N}\cos\theta_i\pm\left(\frac{3}{N}\right)^{\frac{1}{2}}.$$

$\bar{P}$ is the polarization averaged over the production angles. $\bar{P}\alpha$ positive means π's emitted preferentially in the direction $\mathbf{p}_{\pi\ \text{in.}}\times\mathbf{p}_Y$.

The results show a very large, statistically well established anisotropy for the Λ^0, clearly demonstrating parity violation in the decay. For the entire sample $\bar{P}\alpha=+0.40\pm0.11$. For the Σ^- decay no statistically significant anisotropy is observed. The conclusions are strengthened by the very similar results obtained by Crawford *et al.*[6] At a kinetic energy of 0.99 Bev, this group obtains[7] $\bar{P}\alpha=0.51\pm0.15$ for Λ^0 decay, and also no measurable anisotropy for Σ^- decay.

To estimate the anisotropy coefficient, α, itself, we have combined all results available in the *lower* energy interval, where the results of Table II indicate a larger polarization. With our results at 910, 950, and 1100 Mev, with those of Berkeley at 990 Mev,[6] and with the result $\bar{P}\alpha=0.465\pm0.34$ of Adair and Leipuner at 950 Mev,[8] one obtains $\bar{P}\alpha=0.52\pm0.10$. To find α it is necessary to know P. This is not possible at present; however, it is possible to fix an *upper limit* for $|\bar{P}|$ from the observed angular distributions.[9] In this energy region only S and P waves can contribute appreciably to the angular distribution. The cross section then has the form $|a+b\cos\omega|^2+|c|^2\sin^2\omega$ and $\bar{P}=(2\pi^2/\sigma)\,\text{Im}ac^*$. If we then use the fact that the same group of data gives a backward to forward asymmetry for the production of Λ^0's in process (1) of 2.9 ± 0.4, we obtain an upper limit for $|\bar{P}|$: $|\bar{P}|\leq0.78\pm0.03$. This results in a lower bound on $|\alpha|$: $|\alpha|\geq0.67\pm0.13$.

* Results presented at the Venice Conference on Elementary Particles, September 22–28, 1957 (unpublished).

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[7] We have taken the liberty to treat these results somewhat differently than the authors have, and obtain a somewhat altered result. The Λ^0 data consist of 76 clear events (double decays) which give $(3/N)\Sigma\cos\theta_i=0.367\pm0.20$. In addition, there are 277 single Λ^0 events of which, according to the authors, about 15% are θ^0 contaminations, and of the remainder $\sim$25% are Σ^0 contaminations. Since neither contaminant should contribute to the anisotropy, the up-down asymmetry of 0.57 (only the sign of θ has been determined for these events) refers to an effective sample of 177 events: $\bar{P}\alpha=2\times(167-110)/177=0.644\pm0.20$. The combined result is $\bar{P}\alpha=+0.51\pm0.15$. The result obtained by the authors, using only up and down results and neglecting the correlation for contamination, is 0.44 ± 0.11.

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