NOTAS DE FÍSICA

VOLUME IV

Nº 8

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# ÁNGULAR CORRELATION IN THE DECAY OF PIONS AND MUONS*

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Rio de Janeiro, D. F.

(Received 19 May 1958)

## PART I.

## I. ANGULAR CORRELATION BETWEEN MUONS AND ELECTRONS

### 1. INTRODUCTION

Since the discovery[1,2,3] of the angular correlation between the initial momentum $\vec{P}_e$ of the electron and the initial momentum $\vec{P}_\mu$ of the muon in the decay chain:

$$\pi \rightarrow \mu + \nu \qquad I$$

$$\mu \rightarrow e + 2\nu \qquad II$$

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* This work has been published in Part II of Annual Progress Report, September, 1956 - 1957, Cosmic Ray Group, U. of Minnesota, Minn.

+ On leave of absence from C. B. P. F. at the University of Minnesota, Minn.

several groups[4,5,6,7,8,9] have studied the same phenomena using "nuclear emulsions" as detectors. The results of these experiments have been expressed by giving the value of the parameter 'a' which appears in the formula:

$$\frac{\Delta Ne}{\Delta\Omega} = k\left[1 + a\,\frac{\vec{P}_\mu \cdot \vec{P}_e}{|P_\mu|\,|P_e|}\right] \qquad (1)$$

which has been assumed to describe the angular correlation under study.

Table I summarizes the values of 'a' for "nuclear emulsions", published or circulated so far. Assuming that the 'true' value of 'a' is a constant in all exposures, the probability of obtaining as wide a spread of values of 'a' as exhibited in Table I is (chi square test):

$$P = \frac{3}{1000}$$

Such small value of P indicates that it is worthwhile to consider the possibility that 'a' varies according to the conditions of exposure and that one should pursue the matter further.

It is also noticeable that the values of 'a' obtained from pions created and stopped in "large stacks" exposed to (mostly) <u>primary cosmic radiation</u> are the ones that are significantly smaller than the mean value of 'a'.

2. MINNESOTA STACK (M-STACK)

In a previous paper from this laboratory[8], a measurement performed in a 22.4 liter stack (M-stack) was reported and, in view of the fact that the value obtaine for 'a',

$$'a' = -.03 \pm .038$$

differed from the average of all measurements by more than three

TABLE I

| Ref. | Laboratory | Pion producing Particle | 'a' |
|---|---|---|---|
| 2 | Chicago | Cyclotron protons | -0.174 ± 0.038 |
| 4 | Goettingen | " " | -0.095 ± 0.044 |
| 5 | Cambridge I | " " | -0.149 ± 0.033 |
| 5 | Cambridge II | " " | -0.190 ± 0.033 |
| * | Minnesota II | " " | -0.185 ± 0.050 |
| 10 | Rochester | Cosmotron protons | -0.19 ± 0.05 |
| 3 | Rome | Cosmic rays | -0.222 ± 0.067 |
| 7 | Bristol I | Cosmic rays | -0.14 ± 0.07 |
| 6 | Copenhagen | Cosmic rays | -0.17 ± 0.07 |
| 7 | Bristol II | Cosmic rays (G stack) | -0.02 ± 0.07 |
| 8 | Minnesota I | Cosmic rays (M stack) | -0.03 ± 0.038 |

* Measurements reported in Section I-5 of this paper.

| | | |
|---|---|---|
| Weighted means: | All measurements | 'a' = -0.156 ± .012 |
| | Machine-made pions | 'a' = -0.164 ± .015 |
| | Small cosmic ray stacks | 'a' = -0.176 ± .040 |
| | Large cosmic ray stacks | 'a' = -0.027 ± .033 |

standard deviations[9], the possibility of a variation of 'a' with the conditions of exposure was seriously considered. Possible explanations that could not be ruled out at the time were:

a) Anamalous depolarization of the muons due to a difference between the chemical compositon of the emulsions used in the M and G stacks and those used in other experiments.

b) Existence of more than one 'type' (or state) of pions, in which case different results might be obtained, depending on the composition of the pion 'mixture' which is brought to rest in the emulsion. If different 'types' of pions do exist, the composition of the mixture which is brought to rest in the emulsion might change if one varies:

$b_1$) The multiplicity of the events in which pions are created. In machine events the multiplicity is one. In cosmic ray stacks the multiplicity may vary with conditions of exposure and in the M-stack the average multiplicity was 5.

$b_2$) The fraction of the pions which suffer nuclear scattering before stopping in the emulsion. This fraction will increase with the size of the stack.

$b_3$) The angle of emission of the stopped pions relative to the incident particle in the C. M. System. In machine experiments the pions collected come from a well defined backwards angle in the C. M. System. In small cosmic ray stacks only low energy pions will be stopped, which gives a bias in favor of the pions emitted backwards in the C. M. System. In large cosmic ray stacks, a wider spread of angles is accepted.

$b_4$) The nature of the pion-producing particles. In the machine experiments the incident particles are always protons. In cosmic ray stacks, especially in large ones, an appreciable fraction of the incident particles are neutrons and pions.

Since Ref. 8 was sent to press, new results have been published or obtained which allow us to discard some of these possibilities.

## 3. ANOMALOUS DEPOLARIZATION OF MUONS

The Columbia group[11] has measured electronically the assymetry parameter 'a' in a variety of emulsions, including old and new batches, emulsions with and without sensitizers, with and without plastisizers, pure gelatine, and have varied the temperature. All results are consistent with a single value of 'a' $\cong$ - .14.

The Chicago group[12] has tested a sample of the emulsion batch used in the M-stack and found that 'a' $\cong$ - .14.

The possibility of explaining the result of the M-stack by assuming anomalous depolarization due to chemical effects is therefore ruled out.

## 4. MULTIPLE PRODUCTION OF PIONS

The measurements (Ref. Nos. 3, 6 and 7 of Table I) performed in small emulsion stacks exposed to cosmic rays, give an average value 'a' = - .176 ± .040 which is in good agreement with the mean of the values obtained in measurements performed on machine-produced pions: 'a' = -.164 ± .015. These results indicate that multiple production alone cannot explain the low values obtained in the M and G stacks.

## 5. NUCLEAR SCATTERING OF PIONS

In order to check whether the fact that the pions are scattered before being brought to rest will change the value of 'a', we obtained from the University of Chicago a stack of emulsions exposed to a scattered pion beam, as shown in Figure 2. The scanning of the emulsions was done in regions chosen so that the range of pions required that the scattering in the graphite target be inelastic.

The results of the measurement on 1200 π-μ-e events is displayed in Figure 3. A least squares fit of the data gives

$$'a' = -.185 \pm .05$$

This value of 'a' is in good agreement with the mean of all the values of 'a' from machine-produced pions and it indicates that scattering of the pions does not alter the value of 'a', (at least in the direction studied by us).

## 6. ANGLE OF EMISSION OF THE PIONS

In assuming the existence of more than one 'type' (or state) of pion, we did not specify the nature of the new degree (or degrees) of freedom which would be involved in the description of pion phenomena.

If the value of 'a' depends on the angle of emission of the pions, relative to the incident particle in the C. M. System, one may consider the possibility that one new degree of freedom is of the nature of a spin.

Pions are assumed to have spins equal to zero (pseudo-scalar particles) but, in our opinion, this fact is not yet completely established. In particular, the argument which is generally given[13] in favor of S = 0 is based on the study of the reaction

$$P + P \longrightarrow D + \pi^{+} \qquad \text{(production)} \quad III$$

and its inverse

$$D + \pi^{+} \longrightarrow P + P \qquad \text{(absorption)} \quad IV$$

The cross sections for the two processes are related by the principle of detailed balance and in the center of mass system[15]

$$\frac{\sigma(\text{production})}{\sigma(\text{absorption})} = \frac{3\ (2S + 1)k^2}{2K^2} \qquad (2)$$

The experimental results[14,15] agree with S = 0 in equation (2) but it has been pointed out[16] that the factor (2S + 1) does not enter in equation (2) if the pions are polarized at production and if the absorption is studied with polarized pions, and consequently, in such a situation, the spin of the pion could not be obtained from the study of reactions III and IV.

We therefore believe that the question of the spin of the pion is not settled and that it is pertinent to try to establish by other means the validity of the assumption that S = 0.

## PART II

## II. ANGULAR CORRELATION BETWEEN PIONS AND MUONS

### 1. INTRODUCTION

In 1948 Wentzel[17] pointed out that if the pion has a spin $S \neq 0$ and is polarized relative to the direction of the initial nucleon beam, one would expect an anisotropy in the angular distribution of the $\pi \rightarrow \mu$ decays.

The only measurements with reasonable statistics on the angular distribution in $\pi \rightarrow \mu$ decays have been made by Peterson[18]. According to his results the angular distribution deviates from isotropy and "if the true distribution were isotropic, then the probability that the observed distribution would occur is only 4.5 percent. Further, this does not take account of the fact that the extreme points are grouped together. An arbitrary division of the angular distribution (which happens to correspond to a forward-backward separation with respect to the proton beam) at $135^\circ$ into two hemicircles gives a ratio of $1.41 \pm .13$ or a probability of only one in 400 of being due to an isotropic distribution."[18]

Apparently Peterson's result has not been taken seriously, possibly because "the angular distribution which he observes is very peculiar and contrary to all theoretical expectations".[19]

In view of the results reported in Part I and because we do not believe that experimental results should necessarily conform to "theoretical expectations", we felt that a further study of the angular distribution of $\pi \to \mu$ decays was imperative and proceeded to do so as described in the next sections.

## 2. CONDITIONS OF EXPOSURE

The emulsions used for the measurements reported in the next sections have not been exposed especially for detecting polarization of the pions. These emulsions had been intended as a test run to compare with the results of Section 5, Part I. Therefore no special precaution was taken to insure a maximum of polarization at production and a minimum of depolarization in extracting, deflecting and slowing down the $\pi$ beam. The conditions of exposure are shown in Figure 4.

The emulsion stack consisted of 16 (6cm x 8cm x 600μm) Ilford $G_5$ pellicles pressed between two aluminum plates and exposed inside a magnetic shield which reduced the magnetic field intensity to about 1/100 gauss. The emulsions were exposed horizontally and the 120 Mev $\pi^+$ entered the emulsions almost perpendicularly to their leading edge after being slowed down by 1 11/16" of copper so as to have a maximum number of pions stopping in the central region of the emulsion.

It should be pointed out that several factors would contribute to reduce any possible effect due to polarization of the pions at production:

a) The angle of acceptance of the shield channel is of the order of $2^{o}$ but, due to the focussing action of the fringing field of the cyclotron, the angle of emission of the pions in the Lab. System has a greater aperture.

b) Due to the Fermi energy of the nucleons inside the target nucleus, the angle of emission of the pions in the C. M. System will vary even if the angle in the Lab. System is fixed.

c) Likewise, a fixed energy of the pion in the Lab. System does not correspond to a unique energy in the C. M. System.

d) The magnetic fields through which the pions travel are not homogeneous. Pions that get to the same point in the emulsions may have gone through any of the variety of orbits in travelling through the cyclotron fringing field, the strong focussing magnet and the final bending magnet. Therefore, an axis of polarization might change its direction in space, due to precession induced by said magnetic fields, and the amount of precession would depend on the orbit followed by the pions on the way from target to emulsion.

## 3. SCANNING AND REJECTION CRITERIA

The measurements were made on seven pellicles. Scanning was limited to the central region of each pellicle — at least 1 cm away from the edges.

Both complete and incomplete $\pi\mu$ were accepted for measurement, provided the $\mu$ ending happened to be more than 30 m$\mu$ away from either surface of the emulsion.

About 3300 πμ were located by <u>area scanning</u> under x15 eyepiece and x12 objective. Area scanning was done moving the plate in the direction perpendicular to the direction of the incoming pion beam and accepting for measurement the π endings which fell within two lines in the eyepiece which were set parallel to the direction of the movement of the plates.

About 3050 πμ were found by <u>line scanning</u> under x15 eyepiece and x25 objective. Line scanning was done by following all tracks of grain density above a fixed value (and appropriate small angle scattering) until they either left the emulsion or came to rest inside it.

In very few cases (of the order of 20), it was not possible to decide by visual inspection whether the pion decayed into a muon or suffered a large angle scattering near the end of its range and subsequently left the emulsion (it could also be a large angle scattering of a muon). Whenever there was doubt, gap counting and delta ray counting were performed in order to distinguish real πμ decays from large angle scatterings.

4. MEASUREMENTS

The measurements were performed only on the m on tracks, using oil objective x100 and x15 eyepiece. The measurements were the following:

a) <u>Longitude</u>. The zero of the eyepiece goniometer scale was set so that a reference hair line was parallel to the normal to the leading edge of the plate (the incoming pion beam made an average angle of about 2.5$^{o}$ with the zero setting). The angle read in the eyepiece goniometer scale, where the hairline was set parallel to the first 30 mμ (or less) of the muon, was recorded as the muon 'projected angle' or 'longitude'. The longitude was read $\pm 1^{\circ}$ from 0 to $360^{\circ}$.

b) Dip. Using the depth (Z) fine focus adjustment, the depth of the muon track was read at the $\pi\mu$ junction and (normally) 60 m$\mu$ away. Whenever the muon track was too steep or exhibited noticeable distortion or scattering, the reading was made at a smaller distance from the junction. The depth readings were made to the nearest division of the focussing barrel ($\sim$ 2 m$\mu$).

c) The thickness of the emulsion was measured on the Z motion about once every 20 $\pi\mu$.

5. ANGULAR DISTRIBUTION IN LONGITUDE

The angular distribution in 'longitude' is shown in Fig. 5.

The meaning of $\phi$ can be understood from Fig. 6. It should be emphasized that the origin for the angle $\phi$, which is the normal to the leading edge of the emulsion, is an arbitrary direction and there is no a priori reason to expect the angular distribution to be symmetrical relative to $\phi = 0$.

The distribution displayed in Fig. 5 shows a deviation from isotropy that is statistically significant:

A Fourier analysis of the data, considering only the first harmonics:

$$\frac{\Delta N}{\Delta \phi} = k\ (1 + a \cos\phi + b \sin\phi) \tag{3}$$

i.e.

$$\frac{\Delta N}{\Delta \phi} = k \left[ 1 + A \cos(\phi + \phi_o) \right] \tag{4}$$

gives

$$\phi_o = -12^{\circ} \pm 15^{\circ}$$

$$A = -.070 \pm .018$$

We have considered the possible systematic effects which might contribute to the observed lack of isotropy:

a) Bias. The distribution obtained by line scanning is consistent with the one obtained by area scanning. One may conceive that an observer misses muons which are ejected in approximately the same direction as the incoming pion if the scanning is done 'by area'; line scanning should eliminate such a bias. The consistency of the results obtained with the two types of scanning leads us to discard bias as having an important contribution to the observed asymmetry. It is also hard to believe that bias could explain the decrease in $\frac{dN}{d\phi}$ from $180^{\circ}$ to $90^{\circ}$.

b) Scattering of pions and muons near the end of their range. Roughly one-half of the $\pi\mu$ are incomplete, i.e., the muon leaves the emulsion before the end of its range. We have said that in only a very small fraction of cases did the observer have doubts as to whether a particular event was due to a $\pi\mu$ decay or to scattering. Still, in order to check further the possibility of scattering contamination, we analyzed the $\phi$ distribution of 2500 complete $\pi\mu$ and obtained

$$\phi_o = 0^{\circ} \pm 20^{\circ}$$

$$A = -.086 \pm .035$$

which is consistent with the values obtained from all the $\pi\mu$.

c) Distortion. If the plates have been badly distorted during processing, and if the vectors of distortion are so distributed as not to average out through the areas and the plates that were scanned, it is possible to obtain an anisotropy and an asymmetry in the measured distribution when observing a distribution which was isotropical in the unprocessed plates. This possibility seems to be confirmed in our case by the variation of the asymetry coefficient A as a function of dip angle of the muon, and we shall consider it further in section 7.

## 6. ANGULAR DISTRIBUTION IN LATITUDE

We define the 'latitude' angle $\lambda$ as the angle between the direction of the muon track as it leaves the pion ending and the plane of the emulsion (which happens to coincide with the plane of production of the pion and with the median plane of the cyclotron and of the focussing magnetic fields), as shown in Fig. 7.

The angular distribution in 'latitude' is shown in Fig. 8 (from $\lambda = -90^{\circ}$ to $\lambda = +90^{\circ}$) and in Fig. 9 (folded around $\lambda = 0$).

The observed deviation from isotropy is statistically significant. Fourier analysis of the data shows that most of the anistropy can be described by the term containing the 4th harmonic and that

$$\frac{\Delta N}{\Delta \Omega} = k\ (1 + B \cos 4\lambda) \qquad (5)$$

with $B = -.106 \pm .018$ gives a reasonable fit.

<u>Instrumental error</u>. In order to check the possibility of instrumental errors, the dip distribution of 2500 electrons arising from $\pi$-$\mu$-e decays found in emulsions exposed to cosmic rays were analyzed in the same way. The distribution in latitude for the electrons is shown in Fig. 10 and can be seen to be almost identical to the distribution in latitude obtained for the muons (Fig. 9).

As the true distribution of the electrons from cosmic ray $\pi$-$\mu$-e decay should be isotropical, we conclude that some instrumental error is causing the departure from isotropy in latitude observed in both cases. We have examined possible sources of instrumental error, but so far it is not understood what causes the apparent decrease in $\frac{\Delta N}{\Delta \Omega}$

for values of $\lambda$ near $0^{o}$ and $90^{o}$.

Bias. We do not believe that the observed results are due to bias in the selection of the events to be measured. First, because area scanning and line scanning show the same effect; second, because in the case of the $\pi$-$\mu$-e decay the event is selected for measurement without looking at the electron track since at the magnification used for scanning the electron track is hardly visible.

Curvature of the field. The effect of the curvature of the field of view has been examined. For tracks with dip up to 40 div ($\sin\lambda \sim 0.8$), the curvature of the field does not come into play since the dips were measured at points equidistant from the center of the field of view. For steeper tracks there is an effect of the curvature of the field, but its magnitude cannot account for the results that were obtained.

Shrinkage factor. The angle $\lambda$ is obtained from the depth measurements by applying the formula

$$\tan\lambda = S \frac{d}{R} \qquad (6)$$

where d is the difference in depth between the pion ending and a point on the muon track at a projected distance equal to R, and S is the shrinkage factor, i.e., the ratio between the thickness of the emulsion at the time of exposure and the thickness at the time the measurements were made.

The thickness of the emulsion at the time of exposure was measured with a depth gage. Several measurements were performed on each emulsion in order to average out non-uniformity.

The average thickness obtained for the 16 emulsion strips is $\bar{t} = 645 \pm 2$ microns. As a check we calculated the value for the density of the emulsion from $\overline{t}$ and the mass and total area of the strips. The result obtained, $\rho = 3.81$ gm/cm$^3$, is in very good agreement with the expected value of $\rho$ for a 60 % R. H.

The thickness of the processed emulsion was measured at the same time as the measurements on the muon tracks. As a precaution, about every 20 muons we made a measurement of the emulsion thickness. In this fashion the lack of uniformity of the emulsion thickness along the plate and variations of the same with R. H. and temperature should have been taken into account.

We estimate that we know the average shrinkage factor for each emulsion within $\pm$ 2% and for the total data within 1%.

If the distribution in $\lambda$ of the muon tracks is isotropical in the unprocessed emulsion, then

$$\frac{\Delta N}{\Delta \sin\lambda} = k = \text{constant} \qquad (7)$$

It can be shown that, if the shrinkage is uniform and distortion can be neglected in the processed emulsion, the use of a wrong shrinkage factor in formula (7) will give a distorted calculated distribution which can be approximated by

$$\frac{\Delta N}{\Delta \sin\lambda} = k\ (1 + E)\ (1 + 2E \sin^2\lambda)^{-3/2} \qquad (8)$$

where $e = \frac{S'}{S} - 1$

S = true shrinkage factor

S' = assumed shrinkage factor.

We conclude that the uncertainty in shrinkage factor cannot account for the observed anisotropy since the distribution described by (8) is <u>monotonic</u> and the maximum variation expected, with a 2 % uncertainty in S, is of the order of 1.5% between $\sin\lambda = 0$ and $\sin\lambda = .5$, while the observed one is of the order of 30%.

Other possible causes of error in our observed distributions are:

a) non-uniform shrinkage

b) folding in of reading errors in d

c) small angle scattering of the muons

d) distortion of the emulsion upon processing.

All these effects are of second order, but a quantitative estimate of their combined action can only be made after the necessary parameters have been obtained from new and appropriate measurements.

7. DISTRIBUTION IN SPACE

The angular distributions considered in sections 5 and 6 are independent. A better way to utilize the information is to study the angular correlation in space.

We did not complete a spherical harmonic analysis of our data because:

a) As shown in section 6, the angular distribution in $\lambda$ cannot be trusted and most of the effect, if not all of it, must be ascribed to instrumental error.

b) The asymmetry coefficient A of formula (4) has been calculated by splitting the data in intervals of latitude. The results, which are displayed in Figure 11, show that the asymmetry increases with latitude and is maximum near the poles. Such a variation of A with latitude leads us to suspect that the greater part, if not the whole effect, is due to distortion of the emulsion, since any distortion would affect steep tracks more than the horizontal ones.

In order to calculate the effects of distortion on our angular distributions, it will be necessary to have a knowledge of the 1st and 2nd order distortion vector, as a function of the position of the pion ending (in the three coordinates).

It should be pointed out that it is difficult to understand the result of the angular distribution in $\phi$ as an effect of distortion alone because the asymmetry is in the same direction (backwards excess) both for upgoing and for downgoing muons.

## 8. CONCLUSIONS

The study of the angular distribution of the muon initial direction in the emulsion is subject to errors that are not understood even qualitatively.

The results obtained with about 6200 $\pi\mu$ decays show that the measured distribution is significantly different from isotropy, both in longitude and in latitude. The distribution in longitude can be approximated by the expression:

$$\frac{\Delta N}{\Delta \Omega} = k \left[1 + A \cos (\phi - \phi_0)\right]$$

with $A = -.070 \pm .018$

$\phi_0 = -12^\circ \pm 15^\circ$

but, because of the peculiar dependence of the asymmetry coefficient on latitude, the departure from isotropy is not believed to be due to a real property of the pions. It is possible that the effect may be understood in terms of distortions introduced in the emulsion during processing, but it seems hard to explain the fact that the asymmetry is in the same direction both for $\lambda > 0$ and for $\lambda < 0$.

The distribution in latitude can be approximated by the expression:

$$\frac{\Delta N}{\Delta \Omega} = k \; ( \; 1 + B \cos 4\lambda)$$

$B = -.106 \pm .018$

and the effect is believed to be due to instrumental errors since one obtains practically the same distribution when studying electrons from cosmic ray $\pi$-$\mu$-e decay.

The angular correlation between electron and muon original moments in $\pi$-$\mu$-e decays from the M-stack is consistent with isotropy.

$$a = -.021 \pm .033$$

and is more than four standard deviations away from the mean of all measurements.

It seems clear that such systematic errors that contribute to the lack of isotropy observed in $\pi \rightarrow \mu$ decay should not produce a noticeable change in the value of 'a' for the angular correlation between muon and electrons in $\pi$-$\mu$-e decay.


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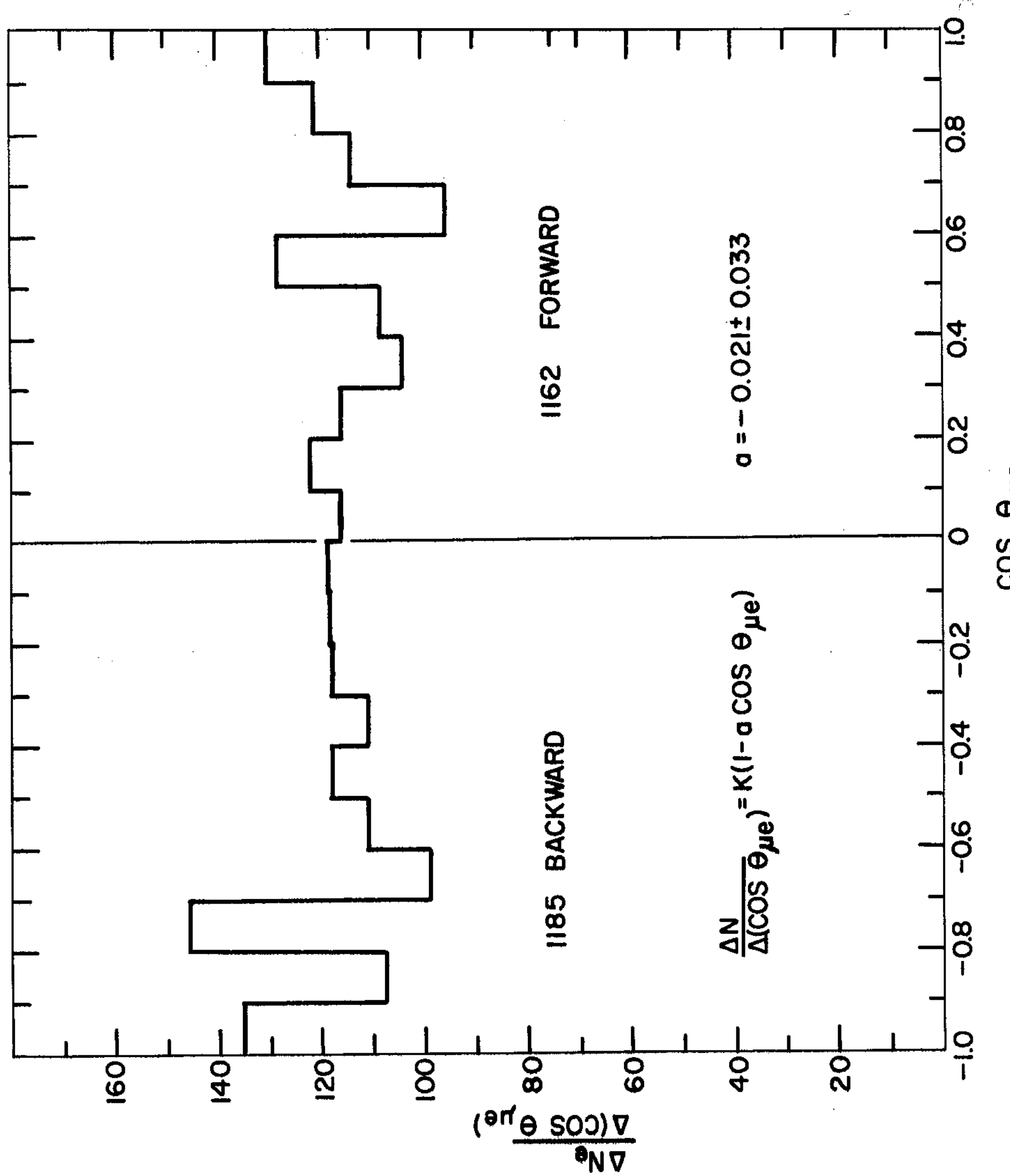



FIG. 1

Distribution in space angle, $\theta_{\mu e}$, between the emission direction of the meson and the electron in the π-μ-e decays observed in a 22-liter stack exposed to cosmic rays at high altitude.

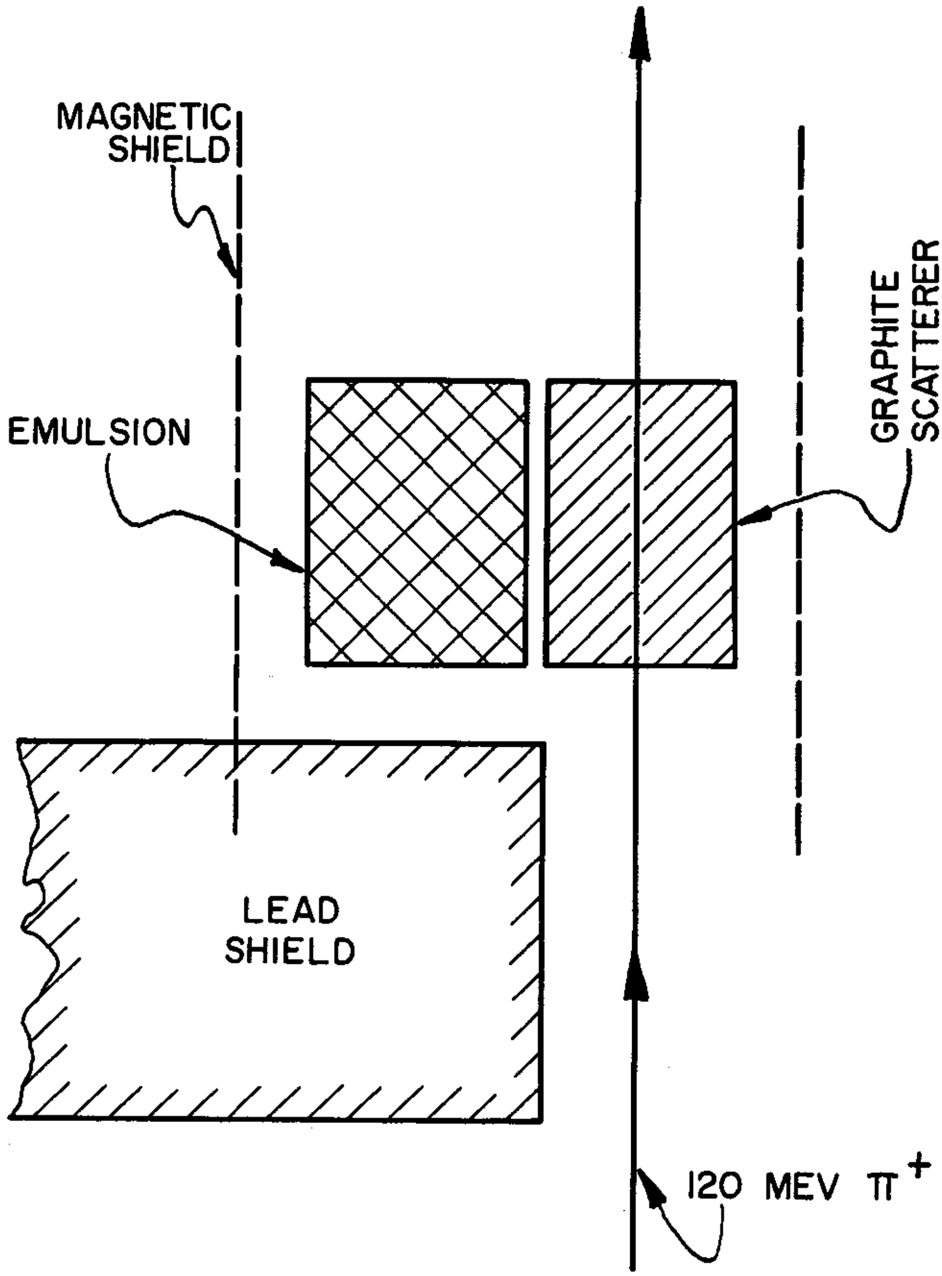



FIG. 2

Exposure conditions for emulsions exposed to a scattered π beam.

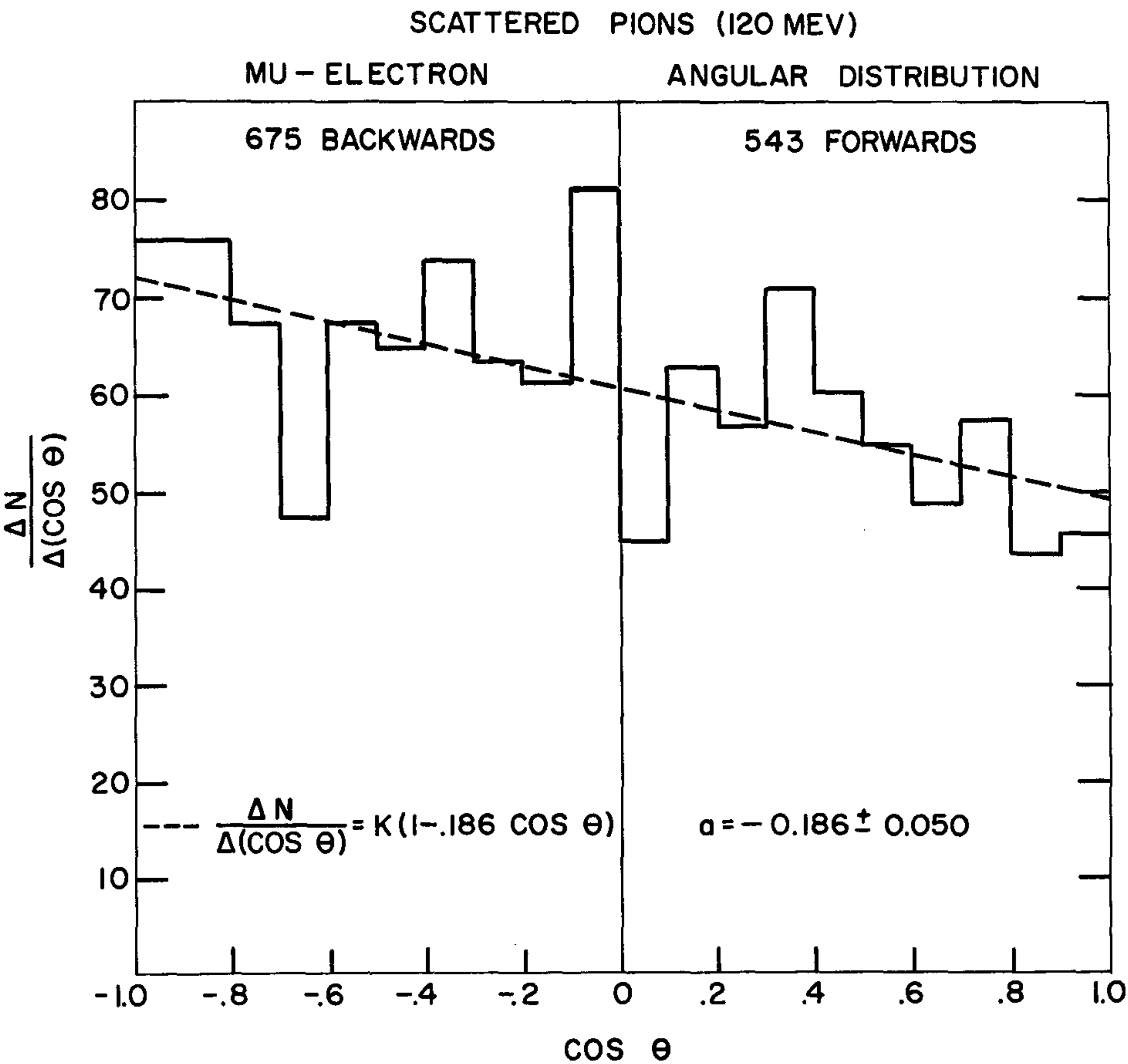



FIG. 3

Distribution in space angle between the emission direction of the meson and electron in the $\pi$-$\mu$-E decays observed in a stack exposed to 120 Mev $\pi$ mesons which have been scattered in a graphite target.

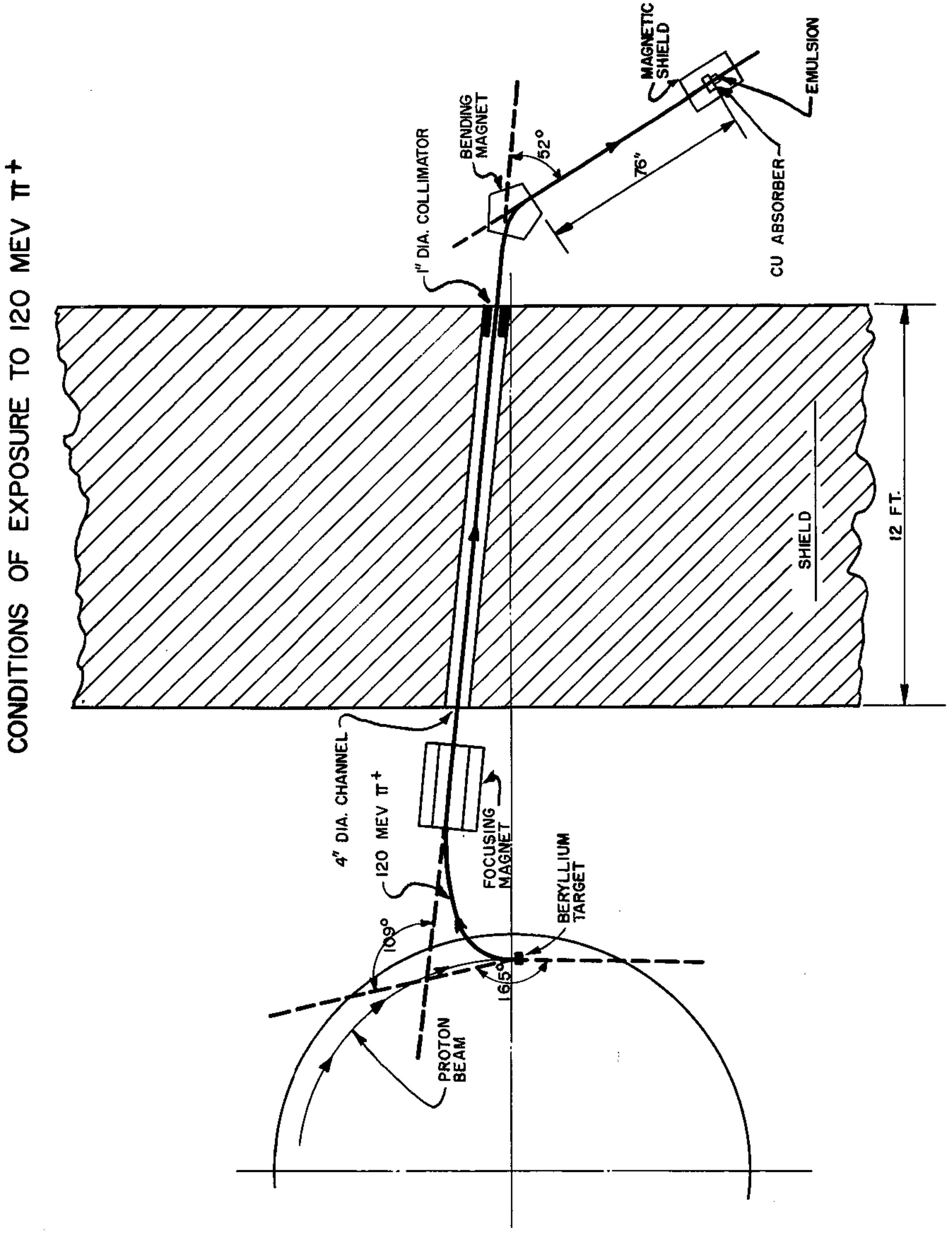



FIG. 4

Exposure conditions of emulsions used to study angular distribution of muons from π-μ decay.

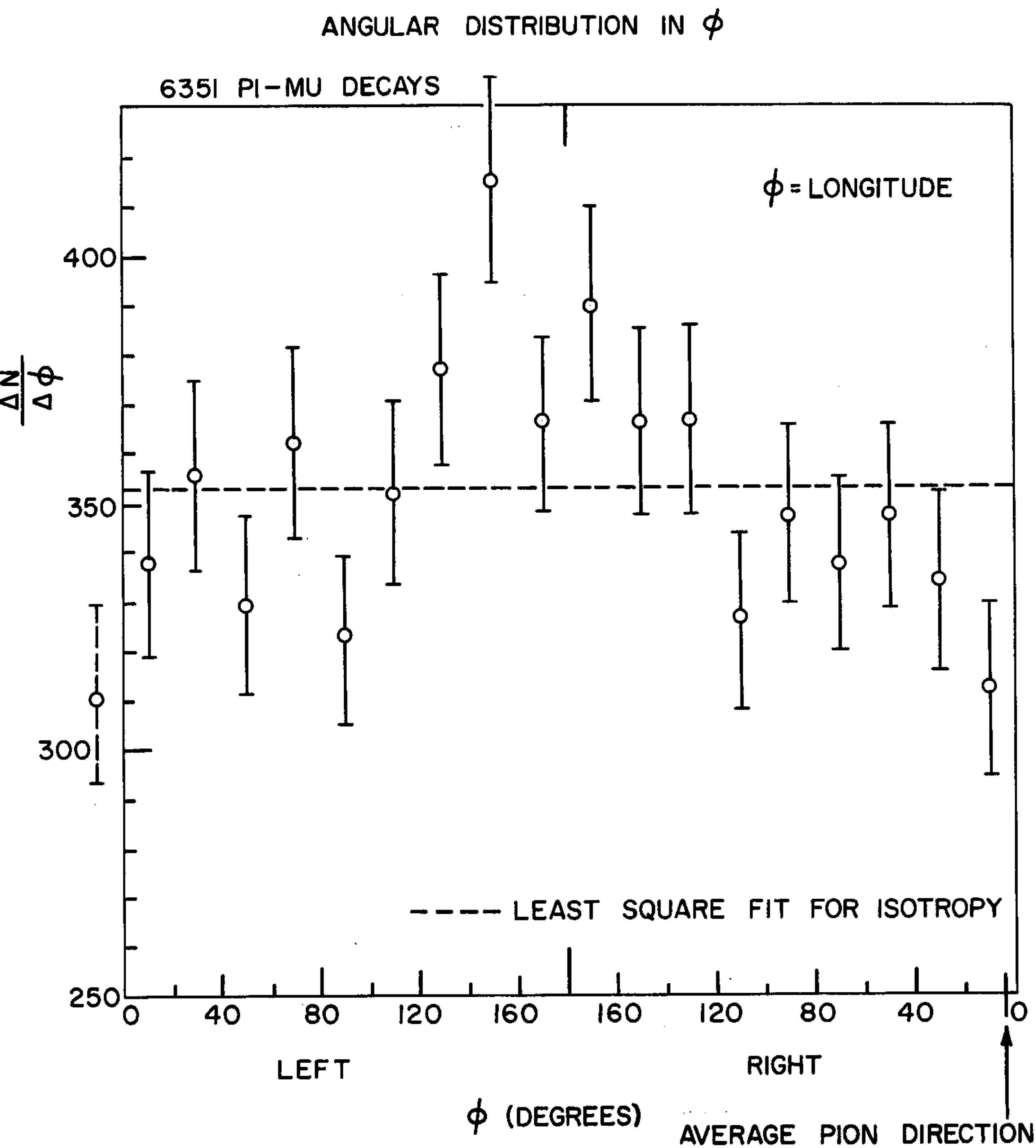



FIG. 5

Angular distribution of the muons in the plane of the emulsion.

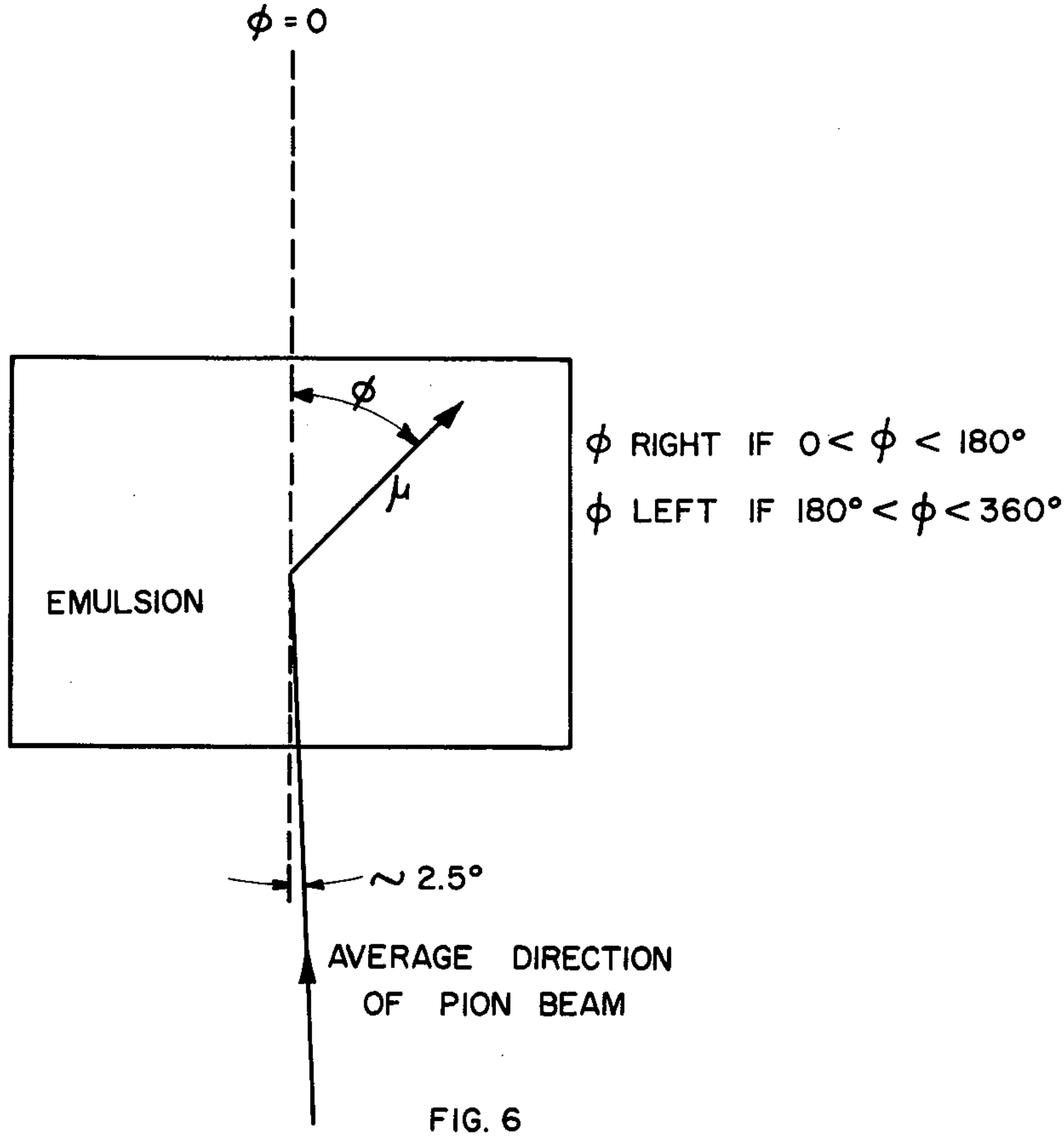
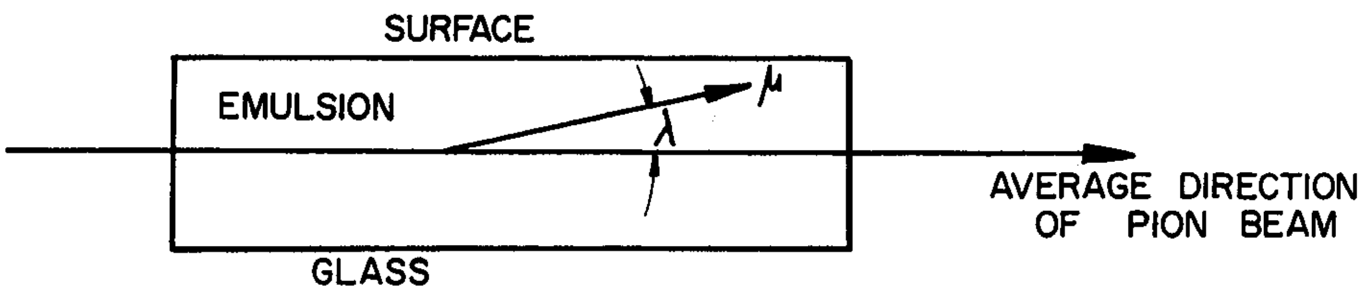



FIG. 6

Projection view in the plane of the emulsion of the $\phi$ measurement made on the muon.




$\lambda > 0$ IF TRACK GOES TOWARD SURFACE

$\lambda > 0$ " " " " GLASS

FIG. 7

Cross section view in the vertical plane containing the muon initial direction showing the measuring convention for $\lambda$.

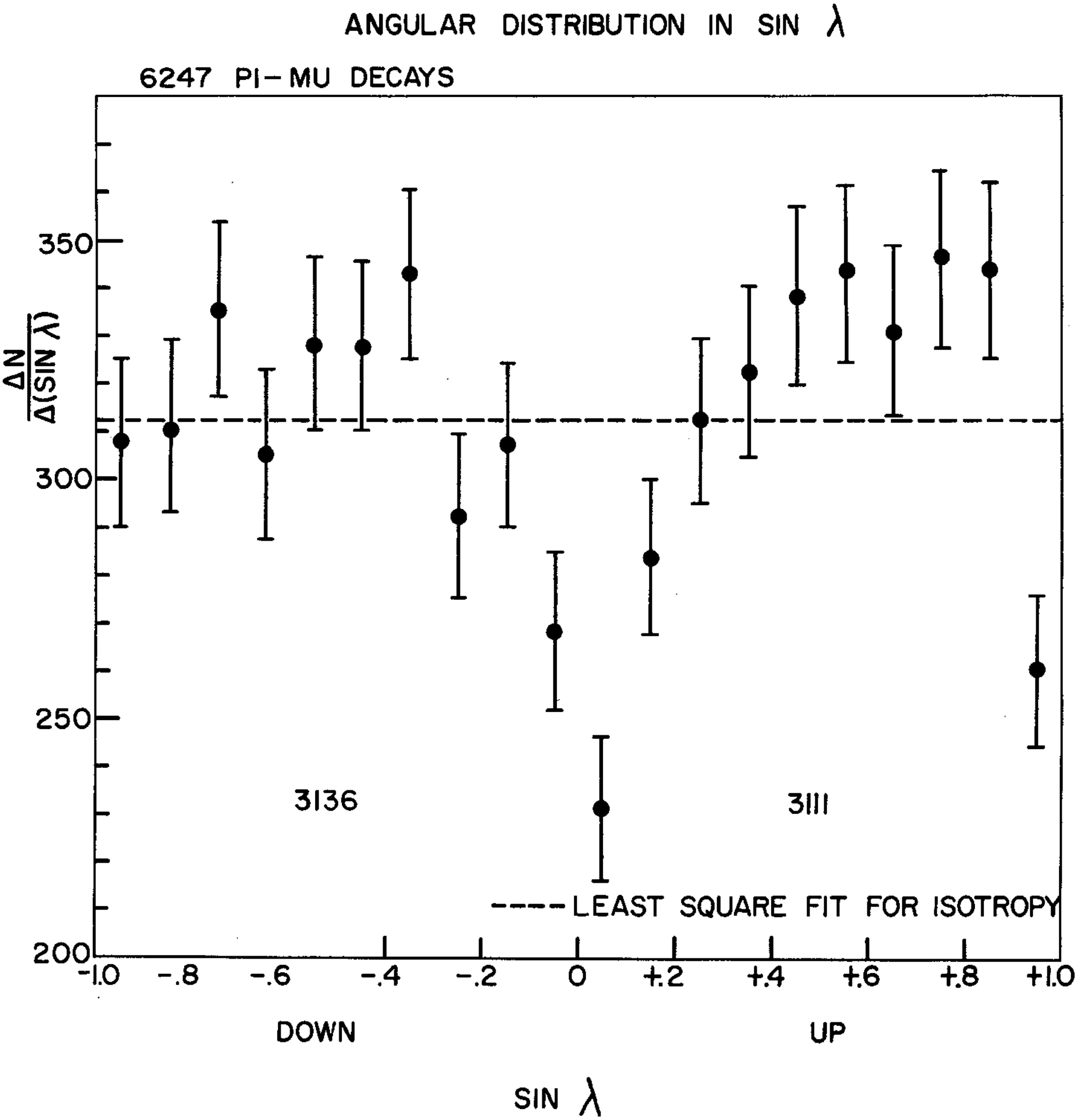



FIG. 8

Angular distribution of the muons in the Z plane of the emulsion.

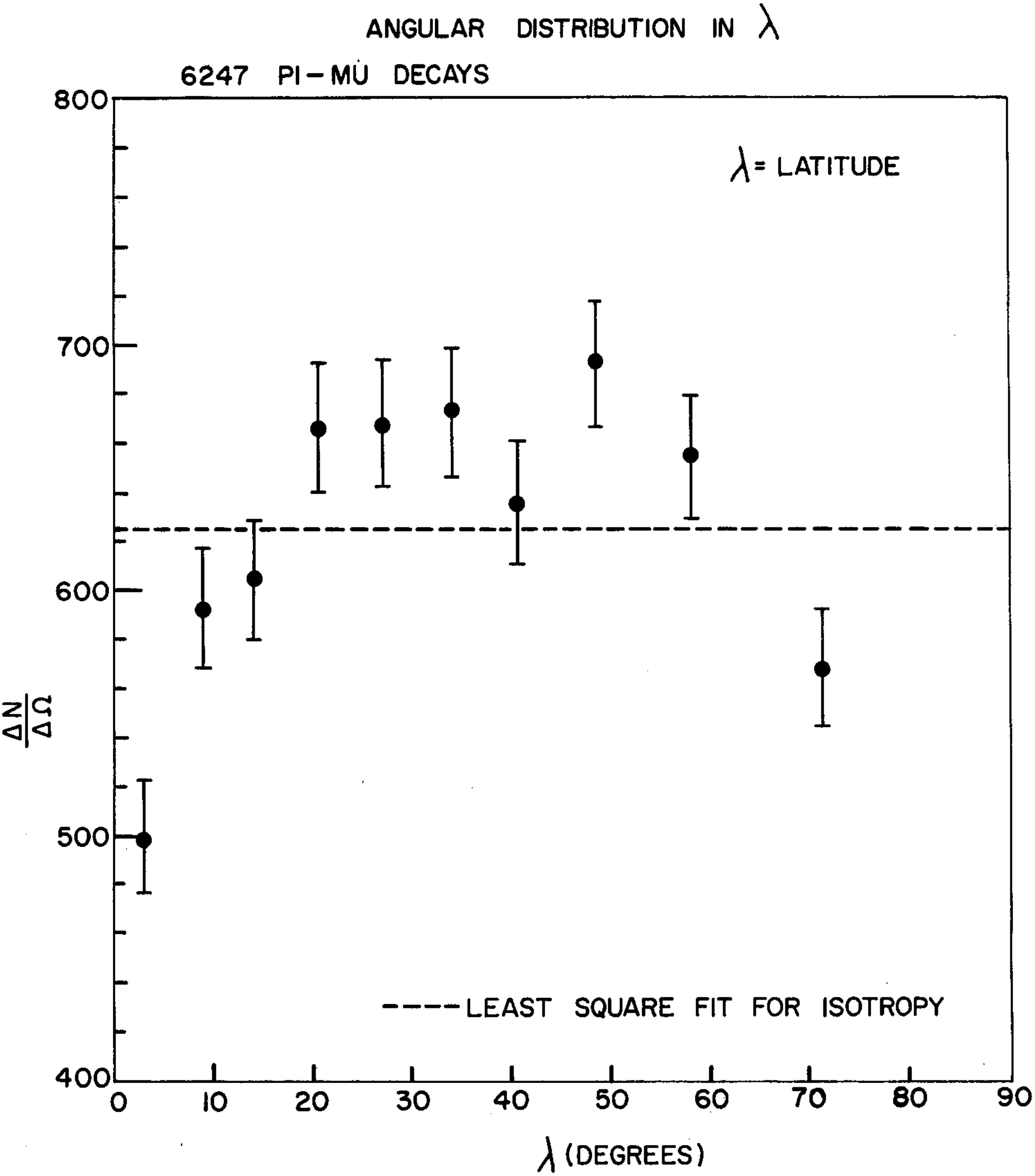



FIG. 9

Angular distribution of the muons in the Z plane of the emulsion folded around $\lambda = 0$.

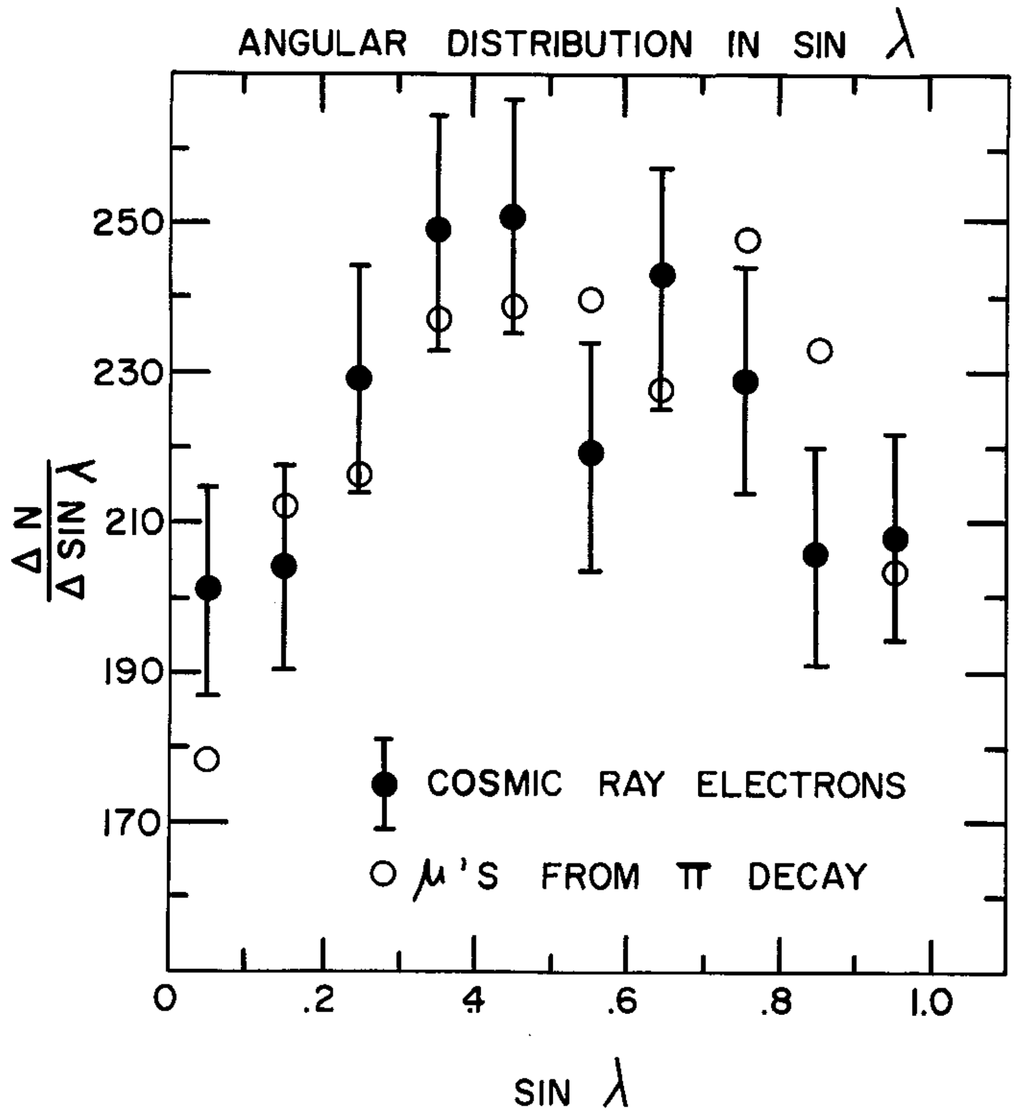



FIG. 10

Comparison of the angular distribution in the Z plane of the emulsion for the muons from the π-μ decay and the electrons from π-μ-e decays.

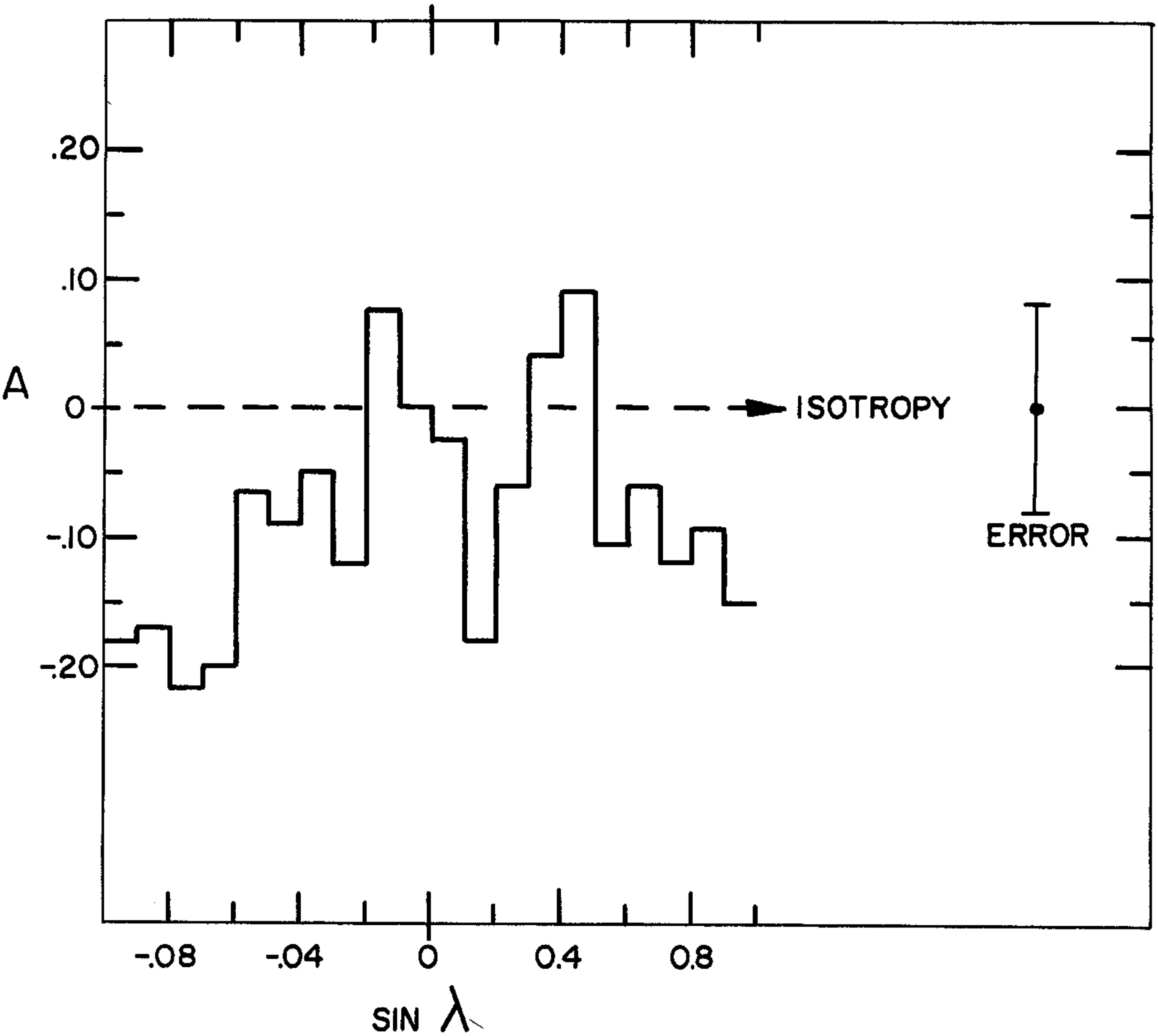



FIG. 11

Variation of the asymmetry coefficient with λ for 6200 π-μ decays of 120 Mev π mesons from the Chicago machine.