**Title**
FORM OF THE INTERACTION IN LAMBDA-HYPERON BETA DECAY



**Authors**
Ely, Robert P.
Gidal, George
Kalmus, George E.
et al.

**Publication Date**
1964-09-17

UCRL-11672

# University of California

# Ernest O. Lawrence Radiation Laboratory



FORM OF THE INTERACTION IN LAMBDA-HYPERON BETA DECAY

Berkeley, California

## DISCLAIMER

UCRL-11672

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

# FORM OF THE INTERACTION IN LAMBDA-HYPERON BETA DECAY

Robert P. Ely, George Gidal, George E. Kalmus, Wilson M. Powell
William J. Singleton, Cyril Henderson, David J. Miller,
and F. Russell Stannard

September 17, 1964

# Form of the Interaction in Lambda-Hyperon Beta Decay*

Robert P. Ely, George Gidal, George E. Kalmus,
Wilson M. Powell, and William J. Singleton

Lawrence Radiation Laboratory
University of California
Berkeley, California

and

Cyril Henderson, David J. Miller, and F. Russell Stannard
University College London
London, England

September 17, 1964

## ABSTRACT

The form of the $\Lambda_\beta$ decay interaction was studied by using lambdas produced by stopping $K^-$ mesons in the Berkeley 30-in. propane-freon bubble chamber. A selected sample of 59 $\Lambda_\beta$ decays were analyzed in the $\Lambda$ rest system, and 50 of these were further studied in the laboratory system. The results show that a pure tensor interaction can be ruled out with 98% confidence, and for mixtures of vector and axial vector, $|C_A/C_V|$ is greater than 0.7 with 95% confidence. Scalar and pseudoscalar, either alone or with small admixtures of tensor, cannot be ruled out. Pure axial vector and $V \pm A$ are consistent with the data.

## INTRODUCTION

The results presented here are from a further analysis of the $\Lambda \rightarrow p + e + \bar{\nu}$ events used in finding the $\Lambda_\beta$ branching ratio.[1] $K^-$ mesons from the Bevatron were stopped in the Berkeley 30-in. heavy-liquid bubble chamber[2] filled with a mixture of 24% propane and 76% freon $CF_3Br$ by weight. Of the events used for determining the branching ratio, 59 satisfied the more stringent criteria that were applied. The analysis was done in both the laboratory and $\Lambda$ rest systems. The data show that a pure tensor interaction can be ruled out with 98% confidence, and for mixtures of vector and axial vector, $|C_A/C_V|$ is greater than 0.7 with 95% confidence. Equal amounts of scalar and pseudoscalar, either alone or with small admixtures of tensor, cannot be ruled out. Pure axial vector and $V \pm A$ are consistent with the data.

With unpolarized lambdas, our statistics were too small to find the sign of $C_A/C_V$ from the lepton spectra.

## SELECTION AND MEASUREMENT OF EVENTS

The $\Lambda_\beta$ decays used to study the interaction were identified by one of two scanning criteria: either the electron track displayed a characteristically high curvature or had a $\delta$ ray greater than 1 cm. The degree of curvature required for acceptance was defined by constructing a radius vector from the $\Lambda$-decay point to a point along the negative track, and requiring the radius vector to pass through a maximum value before reaching the end of the track (Fig. 1). The events identified by $\delta$ rays were required to have an electron track longer than 15 cm . A description of the scanning criteria and background studies is given in reference 1.

The momentum of the electron, as determined from curvature measurements by using the theory of Behr and Mittner[3] or by total shower length, was accurate to 37% at best. Center-of-mass reconstruction therefore depended strongly upon accurate measurements of the proton momentum. For this reason all events with protons which did not stop in the chamber were eliminated. The direction of the proton and the $\Lambda$ are also very critical input parameters in the reconstruction. To ensure that the proton-$\Lambda$ angle was reasonably well determined (to approximately 5 deg), a cutoff of 0.5 cm was applied both to the $\Lambda$ length ($L_\Lambda$ in Fig. 1) and to the proton length $L_p$.

Fifty events were identified by electron curvature and nine by $\delta$ rays. Each $\Lambda_\beta$ event was measured at least twice and spatially reconstructed. Mean values of the quantities calculated from the different measurements of each event were used, which effectively increased the measurement accuracy.

In addition to the $\Lambda_\beta$ decays, a sample of 770 normal ($\Lambda \rightarrow p + \pi$) decays were measured and fitted to give more information about the validity of assigned errors and to provide a lambda momentum spectrum.

## ANALYSIS OF THE FORM OF THE $\Lambda_\beta$ INTERACTION

The $\Lambda$ momentum could not be calculated from production kinematics, because of formation of the $\Lambda$'s on heavy nuclei. The conservation of energy and momentum at the $\Lambda_\beta$ decay vertex gave a zero-constraint situation with two solutions for the $\Lambda_\beta$ momentum. Since there was no way of choosing between the two solutions, they were treated with equal weight. For about 40% of our events, complex solutions occurred, due to measurement errors. Usually this happened because the proton or electron transverse momentum was measured to be greater than the maximum theoretical value of 163 MeV/c. For these cases, the measured quantities were adjusted according to their errors by a least-squares procedure until the discriminant became zero and a single real solution was obtained.

In the $\Lambda$ rest system, the parameter most sensitive to the form of the $\Lambda_\beta$-decay interaction is the kinetic energy of the proton $T_p^*$ (see for example reference 4). However, the distribution of $T_p^*$ is independent of interference effects between V and A, and therefore cannot be used to determine the sign of $C_A/C_V$.

The lepton spectra, though dependent on the form of the interaction and on interference effects, are dominated by the phase-space factor. This, coupled with the poor measurability of the electron momentum, precluded a determination of the sign of $C_A/C_V$ in this experiment.

Results independent of electron momentum were obtained in the laboratory system from the distributions of proton transverse momentum ($P_t$) and of the angle $\Phi$ between the proton and electron measured in the plane perpendicular to the $\Lambda$ line of flight (Fig. 2). These quantities were sensitive to the form of the interaction and had the advantage of having no two-solution ambiguity and requiring no fitting.

## STUDY OF BIASES AND EXPERIMENTAL RESOLUTION

Distributions of the $\Lambda_\beta$ decay parameters in the laboratory system were biased by the selection criteria and by measurement errors, and in the $\Lambda$ rest system also by the two-solution ambiguity and the fitting procedure. To compensate for these biases, we modified the theoretical distributions for different forms of the interaction by a Monte Carlo program which generated events under simulated experimental conditions. The experimental results were then compared to the modified theoretical curves.

The program initiated each random decay in the $\Lambda$ rest system, according to a given matrix element. The proton and electron were then transformed to the laboratory system by using a $\Lambda$ momentum chosen at random from a sample of 770 measured $\Lambda$ decays. At this point the chamber geometry and range-energy relations were introduced, and the protons were required to stop within the chamber. Cutoffs were then applied on $L_p$ and $L_\Lambda$ and each event was weighted according to the electron-detection efficiency curve.[1] Typical angle and track curvature errors were assigned by random choice on the assumption that they were normally distributed.

The program was checked by having it produce normal $\Lambda$ decays, with the "experimental" errors and cutoffs on $L_p$ and $L_\Lambda$. The resulting distributions of $P_t$ and $\Phi_{p\pi}$ (the angle between the proton and pion in the plane transverse to the $\Lambda$ direction) agreed well with those from our measured sample of 770 $\Lambda$ decays (see Figs. 3 and 4).

To obtain the quantities in the $\Lambda$ rest system, the same program that had been used for the kinematical reconstruction of the real events was employed to find the two real solutions, or a fitted single solution for each Monte Carlo event.

Monte Carlo runs were made at seven different values of $|C_A/C_V|$ from 0 to $\infty$, i.e. throughout the range from pure vector to pure axial vector. For convenience, the parameter $Y = |C_A| - |C_V| / |C_A| + |C_V|$ was used, so that $Y = -1.0$ for a pure vector interaction, $Y = 0$ for $V \pm A$ and $Y = 1.0$ for pure axial vector. Runs were also made using the tensor interaction and an equal mixture of scalar and pseudoscalar. In each case the induced form factors were assumed to be zero.

## LABORATORY-SYSTEM ANALYSIS

For the laboratory-system analysis, δ-ray events were excluded. The remaining 50 events were all selected on the same basis, namely the $R_{max}$ criterion. This sample was free from background, was selected with a high scanning efficiency, and had an electron-detection efficiency that was well-determined.[1]

Figures 5 and 6 show the data and the modified theoretical curves. The likelihood curves from the $P_t$ and $\Phi$ data are shown in Fig. 7. Of the two quantities, $P_t$ is more sensitive to the form of the interaction, indicated by the higher likelihood ratios of the $P_t$ curve. That the maxima of these two curves do not coincide can be accounted for by a large but reasonable statistical fluctuation. This is seen from the $\chi^2$ analysis summarized in Table I and the comparison of mean values shown in Table II. In both cases the $P_t$ data favor pure axial vector or scalar-pseudoscalar, while the $\Phi$ data favor $V \pm A$. However, $\Phi$ is not sensitive enough to rule out any of the possibilities.

The results from $P_t$ indicate that a pure tensor interaction can be ruled out with 98% confidence. For mixtures of vector and axial vector, $|C_A/C_V|$ is greater than 0.7 with 95% confidence. A scalar-pseudoscalar interaction with small admixtures of tensor cannot be ruled out.

## CENTER-OF-MASS SYSTEM ANALYSIS

The $T_p^*$ spectrum for the 59 events is shown in Fig. 8, together with five of the modified theory curves obtained from the Monte Carlo program. The likelihood ratio between the various V and A theories and pure vector is plotted in Fig. 9 as a function of Y. Figure 10 gives the $\chi^2$ values for a five-cell fit between the $T_p^*$ spectrum and the modified theories. From this, with 95% confidence, we find that $|C_A/C_V|$ is greater than 0.4. A scalar-pseudoscalar interaction, a tensor interaction, or any mixture of the two is quite compatible with these results.

## CONCLUSION

Results of the two analyses are consistent with each other and with previous experiments of Baglin et al.[5] and Lind et al.[6]

A value of $|C_A/C_V| = 0.94$ predicted by Sakurai[7], who assumed a $\Lambda_\beta$ decay branching ratio of $0.82 \times 10^{-3}$, is just compatible with our results. However, the value $|C_A/C_V| = 0.72$ given by Cabbibo[8] is not in good agreement with our result from $P_t$ which favors a predominantly axial vector interaction.

## ACKNOWLEDGMENT

We would like to thank Larry Oswald and the 30-in. chamber crew for all their efforts.

## FOOTNOTE AND REFERENCES

* This work was done under the auspices of the U. S. Atomic Energy Commission and the British Department of Scientific and Industrial Research.

1. R. P. Ely, G. Gidal, G. E. Kalmus, L. O. Oswald, W. M. Powell, W. J. Singleton, F. W. Bullock, C. Henderson, D. J. Miller, and F. R. Stannard, Phys. Rev. 131, 868 (1963).
2. W. M. Powell, W. B. Fowler, and L. O. Oswald, Rev. Sci. Instr. 29, 874 (1958).
3. L. Behr and P. Mittner, Nucl. Instr. Methods 20, 446 (1963).
4. L. Egardt, Nuovo Cimento 27, 357 (1963).
5. C. Baglin, V. Brisson, A. Rousset, J. Six, H. H. Bingham, M. Nikolic, K. Schultze, C. Henderson, D. J. Miller, F. R. Stannard, R. T. Elliott, L. K. Rangan, A. Haatuft, and K. Myklebost, Branching Ratio and Form of Interaction for the Beta Decay of the Λ Hyperon, CERN Physics Report 64-12, April 16, 1964.
6. V. G. Lind, T. O. Binford, M. L. Good, and D. Stern, Experimental Investigation of V-A in Leptonic Lambda Decay, University of Wisconsin preprint No. 6, March 23, 1964 (submitted to Phys. Rev.).
7. J. J. Sakurai, Phys. Rev. Letters 12, 79 (1964).
8. N. Cabibbo, Phys. Rev. Letters 10, 531 (1963).

Table I. $\chi^2$ probabilities for different forms of the interaction, from $P_t$ and $\Phi$ data separately.

| | Form of interaction | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Vector | V-.33A | V-.67A | V-A | V-1.5A | V-3A | Axial Vector | Scalar | Tensor |
| $\chi^2$ of $P_t$ distributions | 26.7 | 16.7 | 8.5 | 5.4 | 3.8 | 2.8 | 2.3 | 0.2 | 10.1 |
| Percentile from $P_t$ (%) | << 1 | < 1 | 4 | 15 | 28 | 43 | 50 | 98 | 2 |
| $\chi^2$ of $\Phi$ distributions | 4.3 | 3.0 | 0.25 | 0.07 | 0.24 | 0.54 | 0.75 | 4.29 | 0.25 |
| Percentile from $\Phi$ (%) | 23 | 39 | 97 | >99 | 97 | 91 | 86 | 23 | 97 |

Table II. Mean values of theoretical distributions of $P_t$ and $\Phi$.

| | Form of interaction | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Vector | V-.33A | V-.67A | V-A | V-1.5A | V-3A | Axial Vector | Scalar | Tensor |
| Mean $P_t$ (MeV/c) from modified theoretical distributions | 112 | 108 | 102 | 99 | 97 | 95 | 93 | 85 | 103 |
| Mean $P_t$ from experiment = 86 ± 6 | | | | | | | | | |
| Mean $\Phi$ (deg) from modified theoretical distributions | 141 | 137 | 132 | 128 | 126 | 124 | 123 | 116 | 132 |
| Mean $\Phi$ from experiment = 128 ± 7 | | | | | | | | | |

## FIGURE LEGENDS

Fig. 1. Example of an $R_{max}$ event. The radius vector $\underline{R}$ from the point of decay to a point on the electron track passes through a maximum value.

Fig. 2. Proton transverse momentum and angle $\Phi$ between the proton and electron in the plane transverse to the $\Lambda$ line of flight. The $\Lambda$ is shown moving along the positive z axis before decay. The x, y plane corresponds to the $\Lambda$ transverse plane.

Fig. 3. Transverse-momentum distribution of 544 normal $\Lambda$ decays selected from the sample of 770 measured events by applying cutoffs on $L_\Lambda$ and $L_p$. The broken line is the $P_t$ distribution of 1200 Monte Carlo events normalized to 544. The $\chi^2$ probability for obtaining a worse fit is 30%.

Fig. 4. Distribution of $\Phi_{p\pi}$ from the same events shown in Fig. 3. The $\chi^2$ probability for obtaining a worse fit is 86%.

Fig. 5. Distribution of $P_t$ from 50 $R_{max}$ events. The smooth curves include the experimental resolution and biases.

Fig. 6. Distribution of $\Phi$ from 50 $R_{max}$ events. The smooth curves include the experimental resolution and biases.

Fig. 7. Likelihood curves from $P_t$ and $\Phi$ data from 50 $R_{max}$ events. $Y = (|C_A/C_V| - 1)/(|C_A/C_V| + 1)$.

Fig. 8. Distribution of the proton kinetic energy in the $\Lambda$ rest system for 59 events including $\delta$-ray events. The smooth curves include the experimental resolution, the biases due to track length cutoffs, the two-solution ambiguity, and the effects of the fitting procedure.

Fig. 9. Likelihood curve from $T_p^*$ data for 59 events.

$Y = (|C_A/C_V| - 1)/(|C_A/C_V| + 1)$.

Fig. 10. Chi-square curve from $T_p^*$ data with four degrees of freedom.

$Y = (|C_A/C_V| - 1)/(|C_A/C_V| + 1)$. Values for tensor and scalar-pseudoscalar interactions are shown at the right.

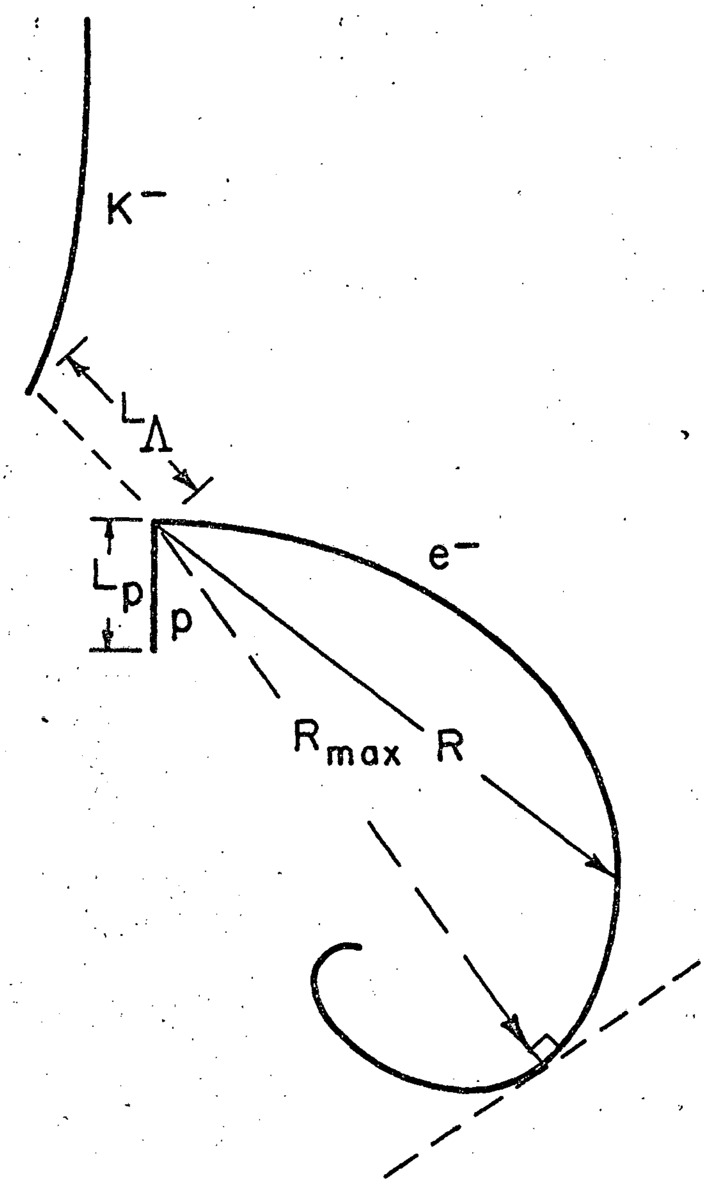



Fig. 1

MUB-4213

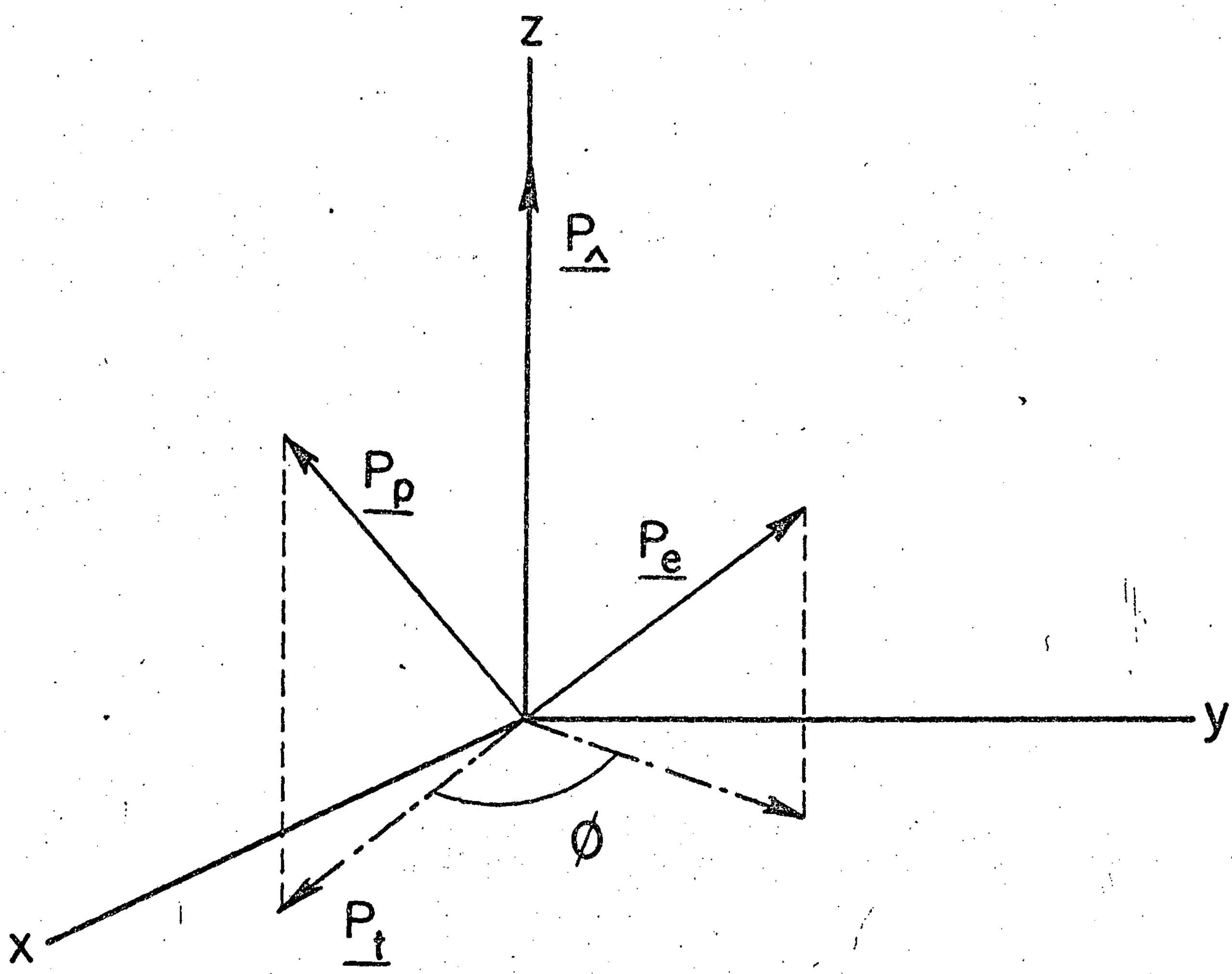



Fig. 2

MUB-2723

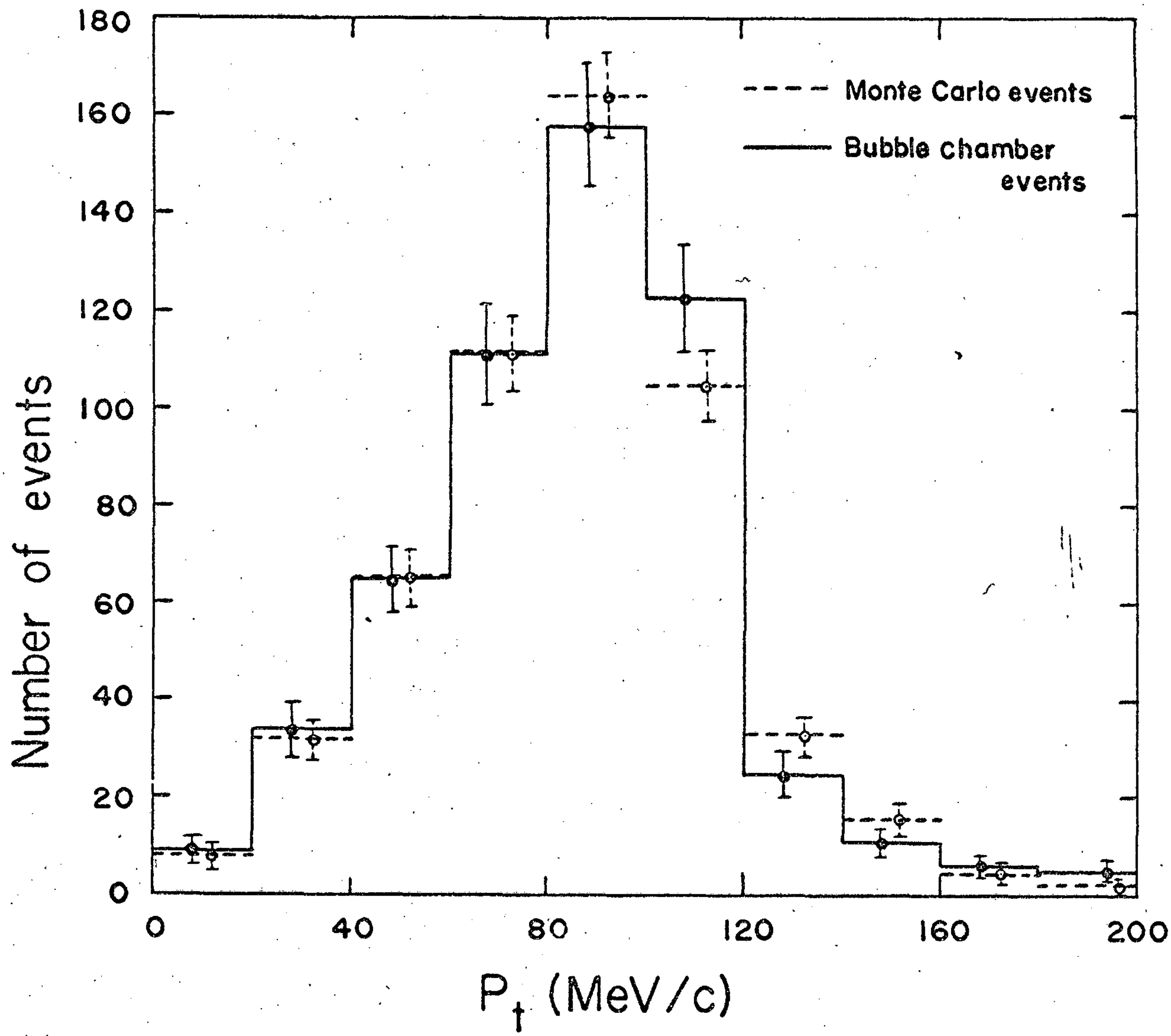



Fig. 3

MUB-2728

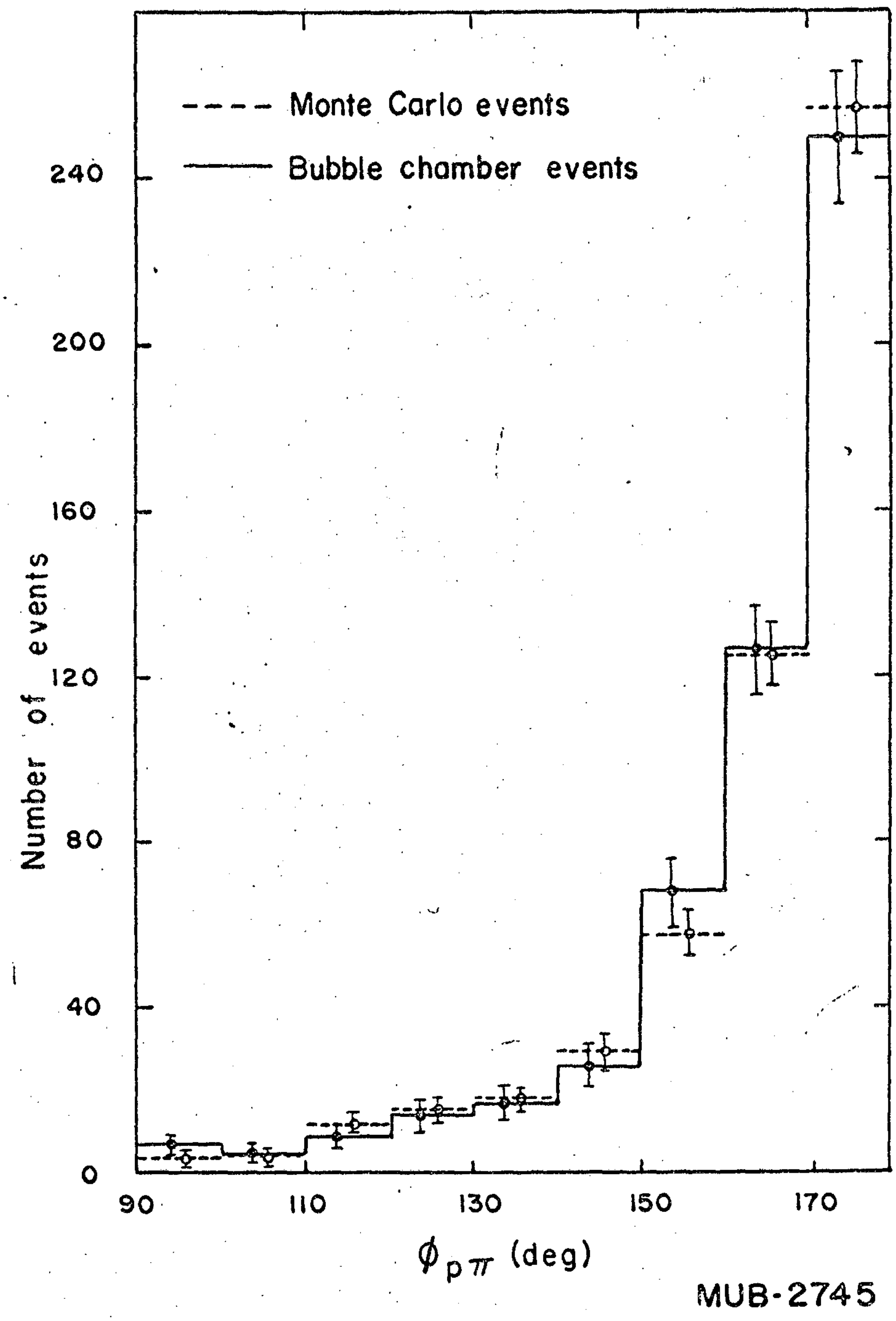

Monte Carlo events
Bubble chamber events
Number of events
0
40
80
120
160
200
240
90
110
130
150
170
$\phi_{p\pi}$ (deg)
MUB-2745

Fig. 4

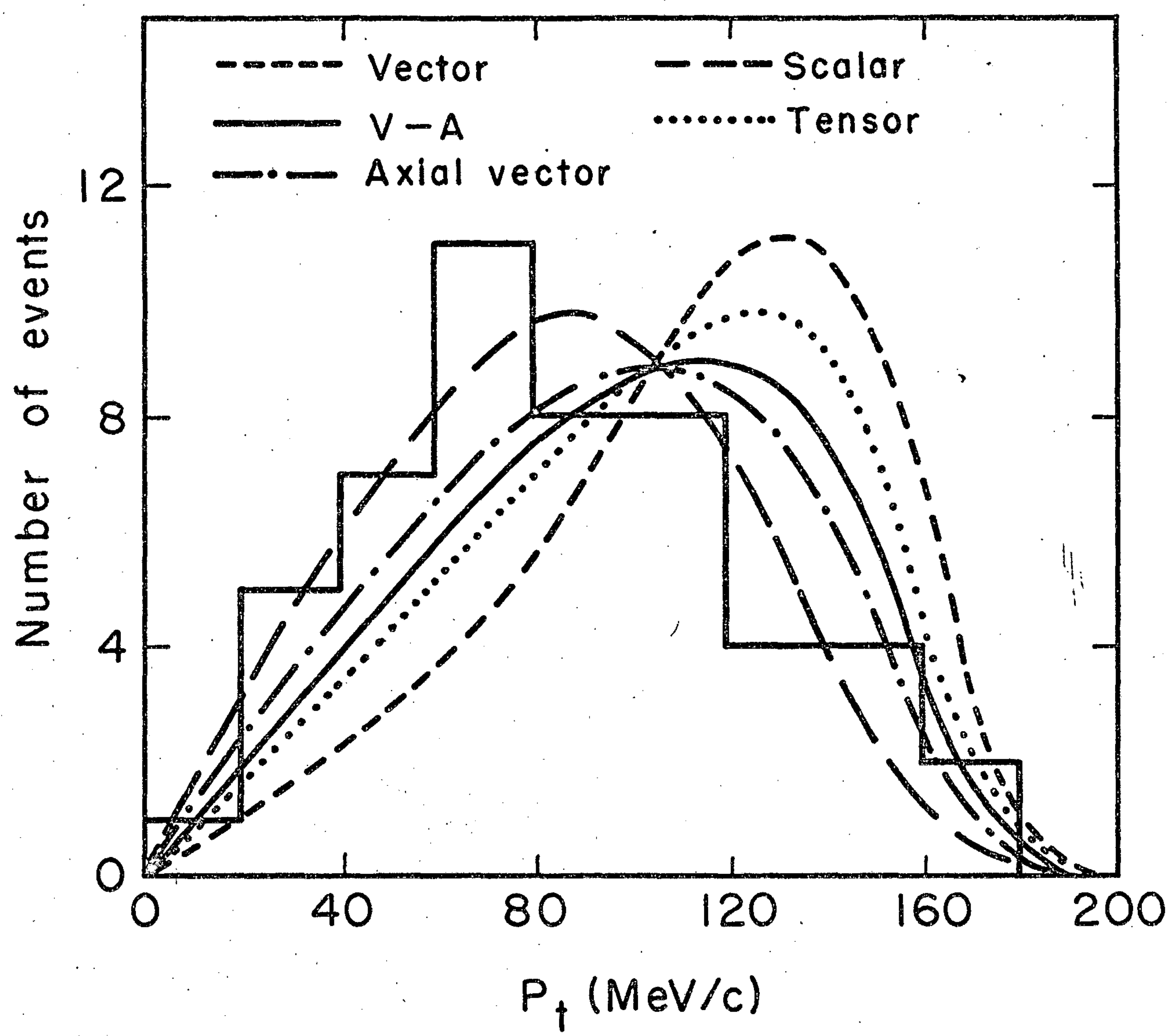



Fig. 5

MUB-4214

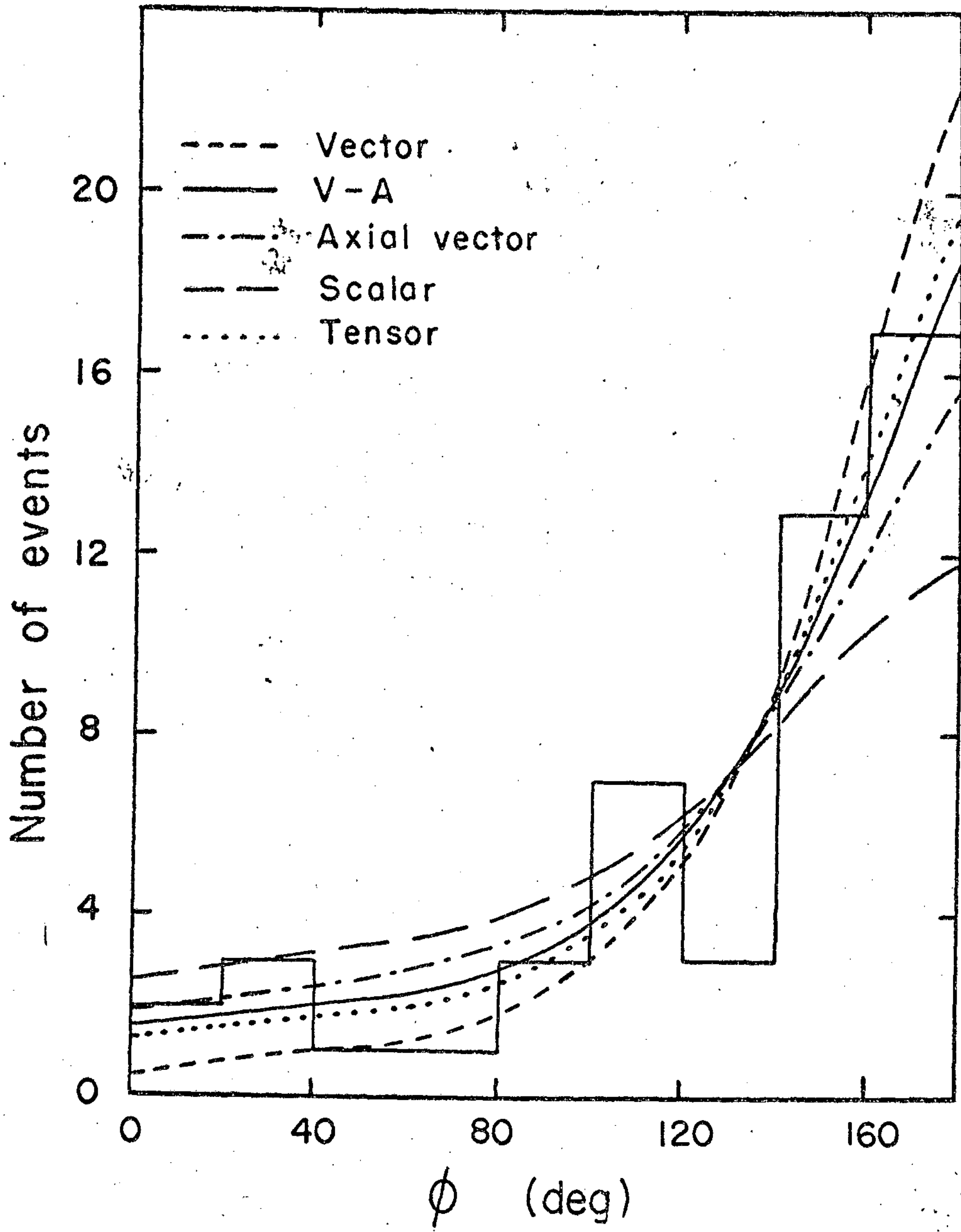
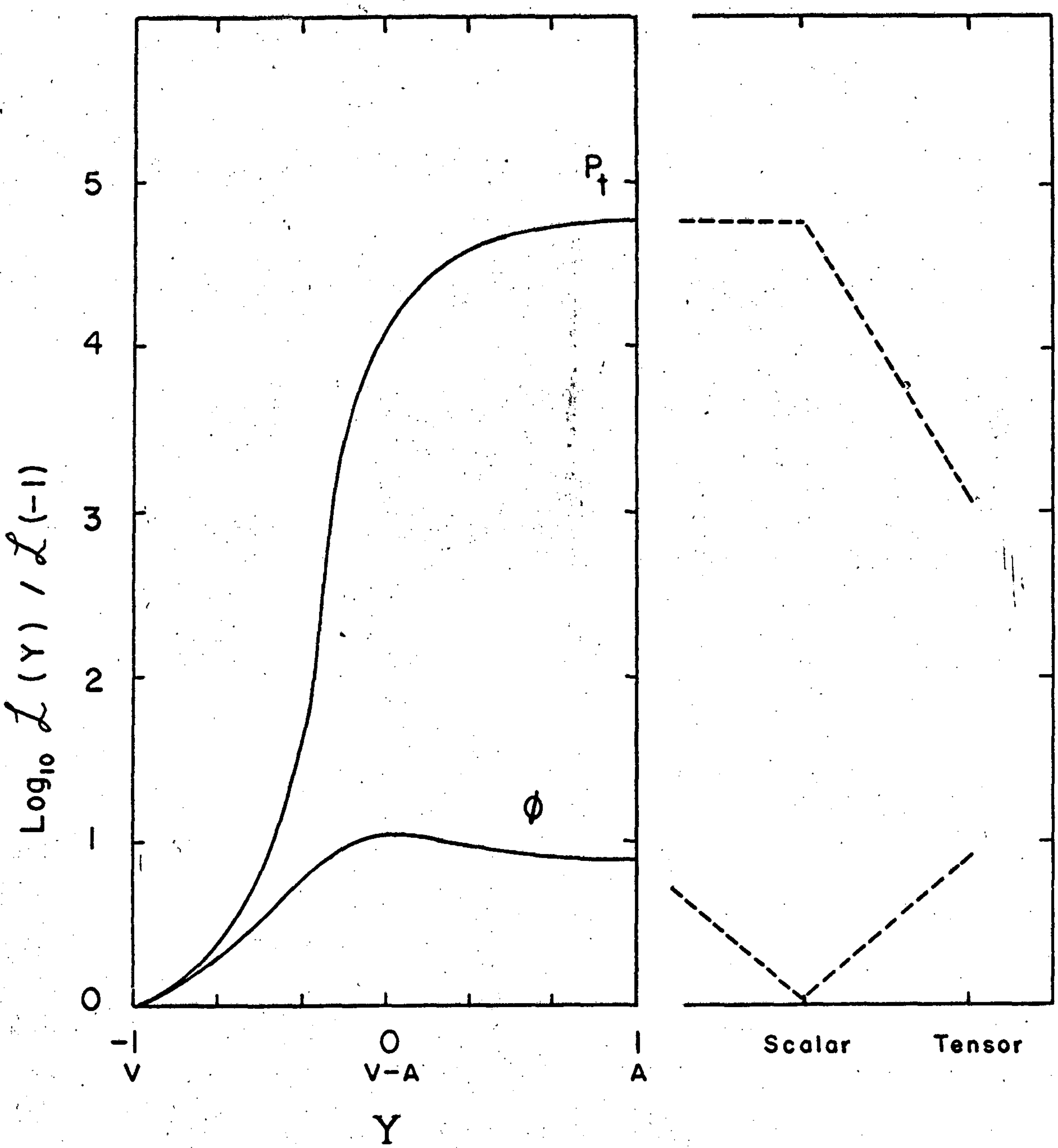



Fig. 6

MUB-2722




MUB-2748

Fig. 7

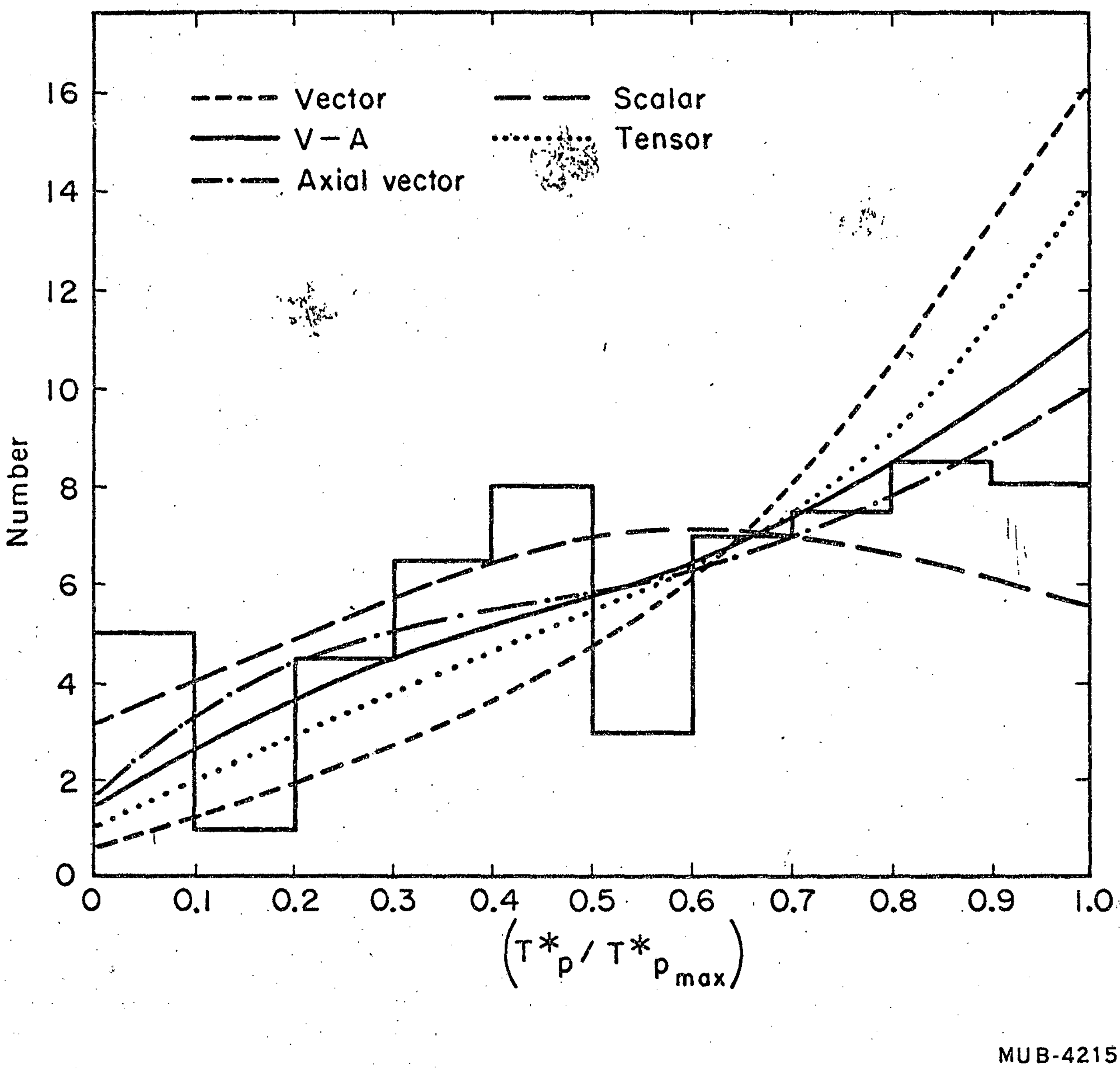

Vector
Scalar
V − A
Tensor
Axial vector
Number
0
2
4
6
8
10
12
14
16
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
(T*p / T*p max)
MUB-4215

Fig. 8

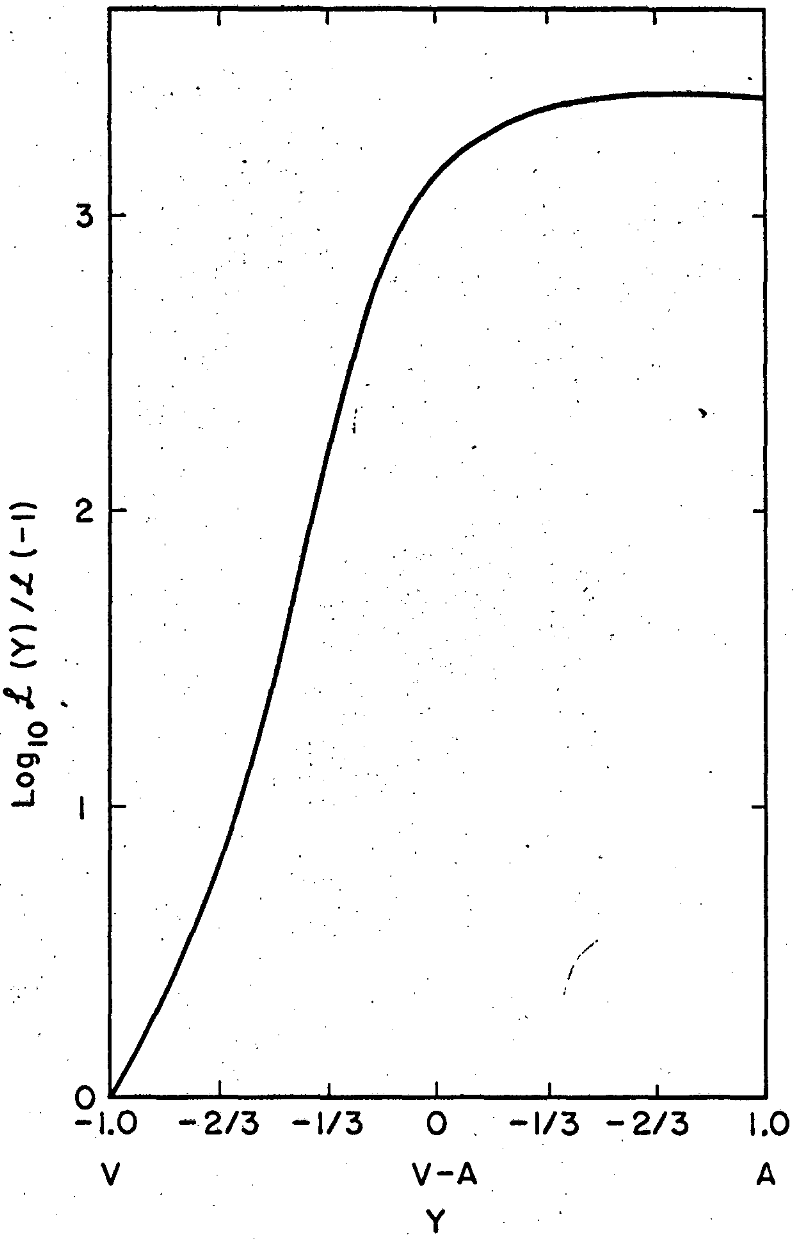
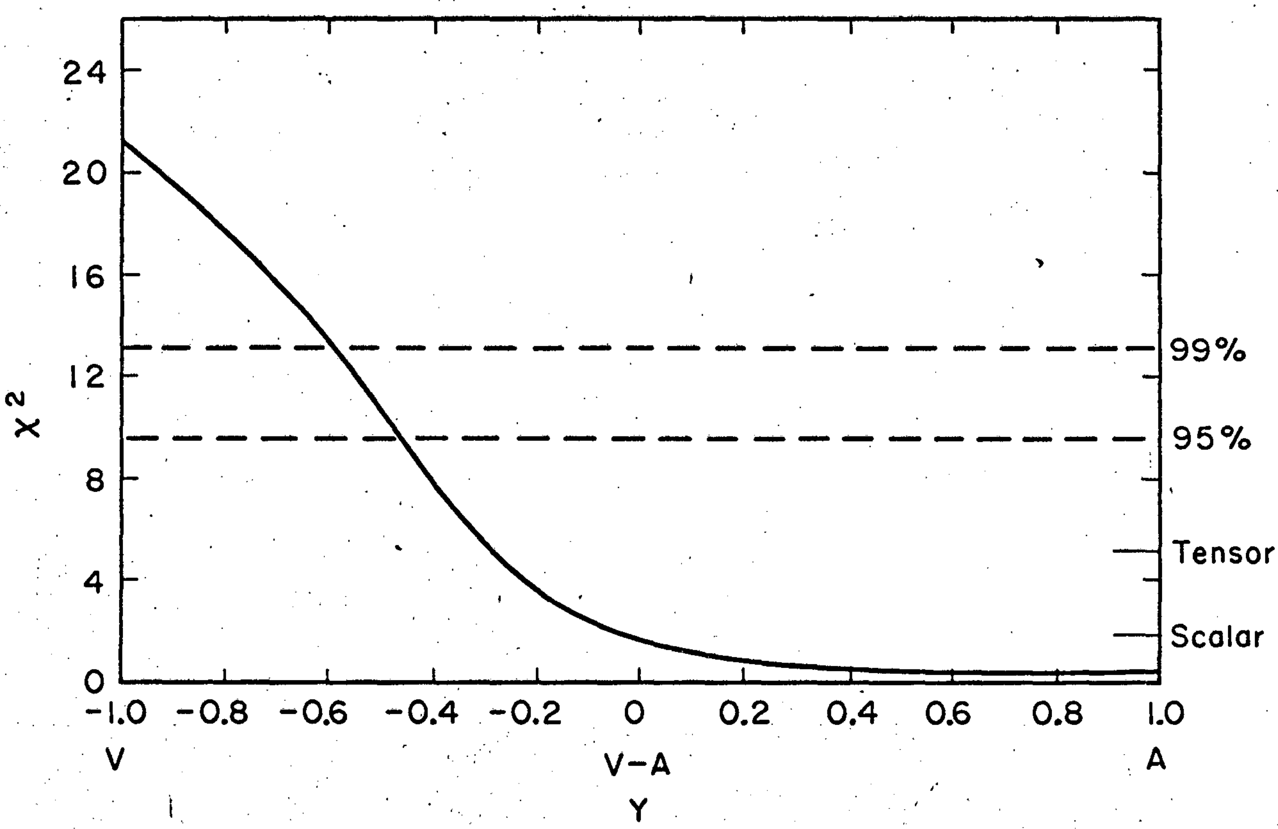



Fig. 9

MUB-4216




MUB-4217

Fig. 10