UCRL-10236

University of California

Ernest O. Lawrence Radiation Laboratory

Berkeley, California

1962 Conference on High Energy Physics, CERN UCRL-10236

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

Ξ^- HYPERONS IN THE REACTION $K^- + p \rightarrow \Xi^- + K^+$

Luis W. Alvarez, J. Peter Berge, George R. Kalbfleisch, Janice Button-Shafer, Frank T. Solmitz, M. Lynn Stevenson, and Harold K. Ticho

June 5, 1962

Ξ^- HYPERONS IN THE REACTION $K^- + p \rightarrow \Xi^- + K^+$ *

Luis W. Alvarez, J. Peter Berge, George R. Kalbfleisch, Janice Button-Shafer, Frank T. Solmitz, and M. Lynn Stevenson

Lawrence Radiation Laboratory
University of California
Berkeley, California

and Harold K. Ticho

University of California at Los Angeles,
Los Angeles, California

June 5, 1962

(To be presented by Luis W. Alvarez)

I. INTRODUCTION

We have been studying the reaction

$$K^- + p \rightarrow \Xi^- + K^+ \tag{1}$$

in the Berkeley 72-inch hydrogen bubble chamber; to date, we have analyzed about 450 events in which the Ξ^- decays into $\Lambda + \pi^-$ and the Λ subsequently decays into $p + \pi^-$. In the momentum range thus far investigated, 1.2 to 1.6 GeV/c incident K^- momentum, the cross section for reaction 1 rises from ≈ 60 to ≈ 200 μb. The angular distributions are characterized by marked forward peaking of the Ξ^- (see Fig. 1).

The decay distributions show a substantial amount of parity violation, indicating the presence of both s- and p-wave amplitudes in the Ξ^- decay; the s-wave seems to dominate over the p-wave. The rest of this paper is devoted to a discussion of the decay distributions.

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

II. Ξ^- DECAY DISTRIBUTION

In what follows we shall assume, for simplicity, that the Ξ has spin 1/2; our data are consistent with that assumption, but we are at present not able to rule out the possibility of higher spin.

If the decay amplitude is written in the form $(S_\Xi - P_\Xi \vec{\sigma} \cdot \hat{\Lambda})$, then the Λ angular distribution is given by

$$I = (1 - a_\Xi \mathcal{P}_\Xi \hat{n} \cdot \hat{\Lambda}), \tag{2}$$

and the Λ polarization by

$$\vec{\mathcal{P}}_\Lambda = \frac{1}{I} \left\{ -a_\Xi \hat{\Lambda} + \mathcal{P}_\Xi \left[(\hat{n} \cdot \hat{\Lambda}) \hat{\Lambda} - \beta_\Xi \hat{n} \times \hat{\Lambda} + \gamma_\Xi \hat{\Lambda} \times (\hat{n} \times \hat{\Lambda}) \right] \right\} . \tag{3}$$

Here $\hat{\Lambda}$ is a unit vector directed along the line of flight of the Λ in the Ξ rest frame; $\mathcal{P}_\Xi \hat{n}$ is the polarization vector of the Ξ, $(|\hat{n}| = 1)$; and a_Ξ, β_Ξ, γ_Ξ are given by

$$a_\Xi = 2 \, \mathrm{Re}(S_\Xi^* P_\Xi)/(|S_\Xi|^2 + |P_\Xi|^2),$$

$$\beta_\Xi = 2 \, \mathrm{Im}(S_\Xi^* P_\Xi)/(|S_\Xi|^2 + |P_\Xi|^2), \tag{4}$$

and

$$\gamma_\Xi = (|S_\Xi|^2 - |P_\Xi|^2)/(|S_\Xi|^2 + |P_\Xi|^2) .$$

Note that

$$a_\Xi^2 + \beta_\Xi^2 + \gamma_\Xi^2 = 1. \tag{5}$$

III. DETERMINATION OF α_{Ξ}

The longitudinal polarization of the Λ from an unpolarized sample of Ξ's is equal to $-\alpha_{\Xi}$ (see Eqs (2), (3)).[1] This polarization can be determined by a measurement of the asymmetry of the Λ decay; the distribution for the proton direction $\hat{p}$, ($|\hat{p}| = 1$) is given by

$$(1 - \alpha_{\Lambda}\vec{\mathcal{P}}_{\Lambda} \cdot \hat{p}) = (1 + \alpha_{\Lambda}\, \alpha_{\Xi}\, \hat{\Lambda} \cdot \hat{p}).$$

This distribution, for our entire sample of Ξ's, is shown in Fig. 2. (Such a complete sample of Ξ's including all production angles must necessarily be unpolarized.) We obtain the value

$$\alpha_{\Lambda}\alpha_{\Xi} = -0.30 \pm 0.08.$$

This is to be compared with the previously reported values, -0.65 ± 0.35 by Fowler et al.,[2] -0.07 ± 0.30 by Alvarez et al.,[3] and -0.64 ± 0.25 by Bertanza et al.[4]

Using the recently reported value $\alpha_{\Lambda} = -0.61 \pm 0.05$,[5] we obtain

$$\alpha_{\Xi} = 0.50 \pm 0.13.$$

IV. SIMULTANEOUS DETERMINATION OF α_Ξ, β_Ξ, AND γ_Ξ

Once α_Ξ has been determined, one can in principle measure the polarization $\mathcal{P}_\Xi$ for a given production angle by observing the "up-down" asymmetry (see Eq. 2). Then one could determine β_Ξ and γ_Ξ by a measurement of the transverse components of the Λ polarization (Eq. 3).

We represent $\mathcal{P}_\Xi(\theta)$ in terms of the amplitudes of a partial-wave analysis, in order to combine the data from all production angles. The probability function for the c.m. production angle $\theta_\Xi^{\text{c.m.}}$ and the decay Λ and the proton directions $\hat{\Lambda}$ and $\hat{p}$ is then

$$f = \frac{1}{D}\frac{d\sigma}{d\Omega}(\theta_\Xi^{\text{c.m.}})(1 - \alpha_\Lambda \vec{\mathcal{P}}_\Lambda \cdot \hat{p})(1 - \alpha_\Xi \mathcal{P}_\Xi(\theta_\Xi^{\text{c.m.}})\hat{n}\cdot\hat{\Lambda})$$

$$= \frac{1}{D}\frac{d\sigma}{d\Omega}(\theta_\Xi^{\text{c.m.}})\left\{1 + \alpha_\Xi\alpha_\Lambda\ \hat{p}\cdot\hat{\Lambda} + \mathcal{P}_\Xi(\theta_\Xi^{\text{c.m.}})\right.$$

$$\left.\times\left[-\alpha_\Xi\hat{n}\cdot\hat{\Lambda} - \alpha_\Lambda\hat{p}\cdot\left((\hat{n}\cdot\hat{\Lambda})\hat{\Lambda} + \beta_\Xi\hat{\Lambda}\times\hat{n} + \gamma_\Xi(\hat{\Lambda}\times\hat{n})\times\hat{\Lambda}\right)\right]\right\}.$$

Here $\hat{n}$ is a unit vector in the direction $\hat{K}_{\text{inc}} \times \hat{\Xi}$. (D is chosen so that the integral of f over all the relevant angles is unity). We can now write a likelihood function for all the events at a given c.m. energy:

$$\mathcal{L} = \prod_{i=1}^{N} f_i ,$$

where $f_i \equiv f(\theta_{\Xi i}^{\text{c.m.}}, \hat{n}_i, \hat{\Lambda}_i, \hat{p}_i)$ is a function of the partial-wave amplitudes, and α_Ξ and β_Ξ; γ_Ξ is determined from α_Ξ and β_Ξ to within a sign.

The bulk of our data is concentrated at 1.51 GeV/c incident K^- momentum. The angular distributions (Fig. 1) suggest that s- and p-waves alone are no longer adequate to describe the reaction in this energy region. We have therefore used s-, p-, and d-waves in the analysis. We have not yet made a detailed study of whether partial waves higher than d are necessary, and how they might affect our conclusions. At momenta other than 1.51 GeV/c there were insufficient data to warrant a partial-wave analysis; on the other hand, these data did contribute significantly to the determination of α_Ξ through the Λ longitudinal polarization. We therefore wrote the likelihood function in the form

$$\mathcal{L}' = \prod_{i=1}^{N} f_i \prod_{j=1}^{M} (1 + \alpha_\Lambda \alpha_\Xi \hat{\Lambda}_j \cdot \hat{p}_j) ,$$

where the sum over i extends over all events at 1.51 GeV/c (N = 207), and the sum over j over all other events (M = 199). We used a search program for the IBM 7090 to determine the values of the parameters which lead to a maximum of $\mathcal{L}'$. Two maxima were found, one corresponding to $\gamma_\Xi = [1 - (\alpha_\Xi^2 + \beta_\Xi^2)]^{1/2}$, and the other to $\gamma_\Xi = -[(1 - (\alpha_\Xi^2 + \beta_\Xi^2)]^{1/2}$, with these results:

γ_Ξ positive solution–

$\alpha_\Xi = 0.45 \pm 0.11$

$\beta_\Xi = -0.63 \pm 0.31$

$\gamma_\Xi = 0.63 \pm 0.31$

γ_Ξ negative solution–

$\alpha_\Xi = 0.38 \pm 0.14$

$\beta_\Xi = 0.31 \pm 0.88$

$\gamma_\Xi = -0.87 \pm 0.31$

The γ_Ξ positive solution gives a larger value of $\mathcal{L}'$ hence a better fit to the data: $\mathcal{L}'(\gamma_\Xi > 0)/\mathcal{L}'(\gamma_\Xi < 0) = 40$. We do not know yet whether these data allow us to rule out the γ_Ξ negative solution.

It is difficult to present the fit to the data graphically, since f is a function of four independent angles. Figures 3AB and 4AB present two 2-dimensional distributions for the γ_Ξ positive and γ_Ξ negative solutions; these may help the reader visualize the data and the quality of the fits.

REFERENCES

1. See also T. D. Lee and C. N. Yang, Phys. Rev. 108, 1645 (1957), R. Gatto, UCRL-3795 (1957), (unpublished); W. B. Teutsch, S. Okubo, and E. C. G. Sudarshan, Phys. Rev. 114, 1148 (1959), and I. Y. Kobzarev, L. B. Okun, and A. P. Rudik, Soviet Phys. - JETP 11, 728 (1960).
2. W. B. Fowler, R. W. Birge, P. Eberhard, R. Ely, M. L. Good, W. M. Powell and H. K. Ticho, Phys. Rev. Letters 6, 134 (1961).
3. L. W. Alvarez, J. Button, G. R. Kalbfleisch, D. H. Miller, A. H. Rosenfeld, M. L. Stevenson, H. K. Ticho, Bull. Am. Phys. Soc. 7, 48 (1962).
4. L. Bertanza, V. Brisson, P. Connolly, E. L. Hart, P. Hough, I. Mittra, G. Moneti, R. Rau, N. P. Samios, I. Skillicorn and S. Yamamoto; M. Goldberg, E. Harth, J. Leitner, S. Lichtman, and J. Westgard, Bull. Am. Phys. Soc. 7, 296 (1962).
5. J. W. Cronin, Bull. Am. Phys. Soc. 7, 68 (1962).
6. We are indebted to Dr. Fernand Grard for the use of his MALIK program; for a description see, A General Program for Statistical Analysis Using the Maximum-Likelihood-Method MALIK Program, Lawrence Radiation Laboratory Report 10153, March 30, 1962 (unpublished).

FIGURE CAPTIONS

Fig. 1. $K^- + p \rightarrow \Xi^- + K^+$ production angular distributions at 1.2, 1.3, 1.4, 1.5, and 1.6 GeV/c, corresponding to total center-of-mass energies of 1895, 1950, 1980, 2025 and 2060 GeV, respectively. The dotted histograms contain only those events for which both Ξ and Λ travelled more than 0.5 cm before decay. The solid curves are corrected for this factor.

Fig. 2. Determination of the longitudinal polarization of the Λ from $\Xi^- \rightarrow \Lambda + \pi^-$ decay. The distribution of protons (in the Λ rest frame) as measured with respect to the flight path of the Λ (in the Ξ rest frame) is $1 + \alpha_\Lambda \alpha_\Xi\ \hat{p} \cdot \hat{\Lambda}$. Here $\hat{p}$ and $\hat{\Lambda}$ are unit vectors of the proton and Λ in those rest frames.

Fig. 3A. The experimental Λ decay distribution is compared to $\left(1 - \alpha_\Xi \mathcal{P}_\Xi\ (\theta_\Xi^{\,c.m.})(\hat{n} \cdot \hat{\Lambda}\right)$ where $\mathcal{P}_\Xi(\theta_\Xi^{\,c.m.})$ is a function of the s, p, and d partial-wave amplitudes for the γ_Ξ positive solution. Because of the $\theta_\Xi^{\,c.m.}$ dependence of $\mathcal{P}_\Xi$, we have divided the data into six equal $\cos \theta_\Xi$ c.m. intervals. The numbers that appear in each subinterval are the number of events that have decay lengths for both Ξ and Λ greater than 0.5 c.m. The height of each histogram element has been corrected for the detection efficiency. The smooth curves are the best fit solution.

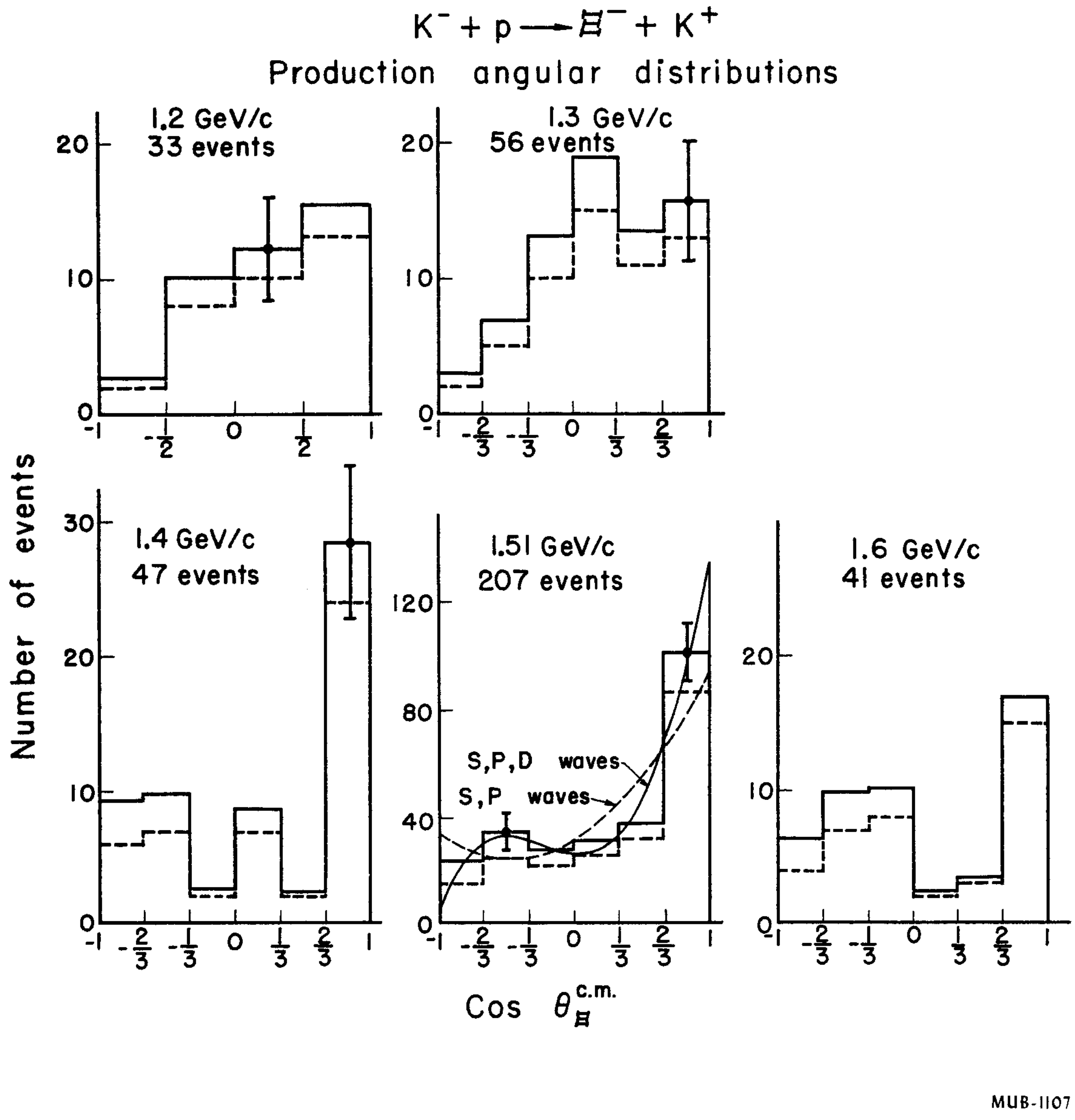
Fig. 3B. The experimental Λ decay distribution is compared to

$$\left(1 - \frac{\pi}{4} \alpha_\Lambda\ \gamma_\Xi \mathcal{P}_\Xi\ (\theta_\Xi^{\,c.m.}) \cdot\ \hat{p} \cdot (\hat{\Lambda} \times \hat{y})\ \right),$$

where $\hat{y}$ is a unit vector in the direction $\hat{n} \times \hat{\Lambda}$, and $\mathcal{P}_\Xi\ (\theta_\Xi^{\,c.m.})$ is a function of s, p, and d wave partial-wave amplitudes for the γ_Ξ positive solution.

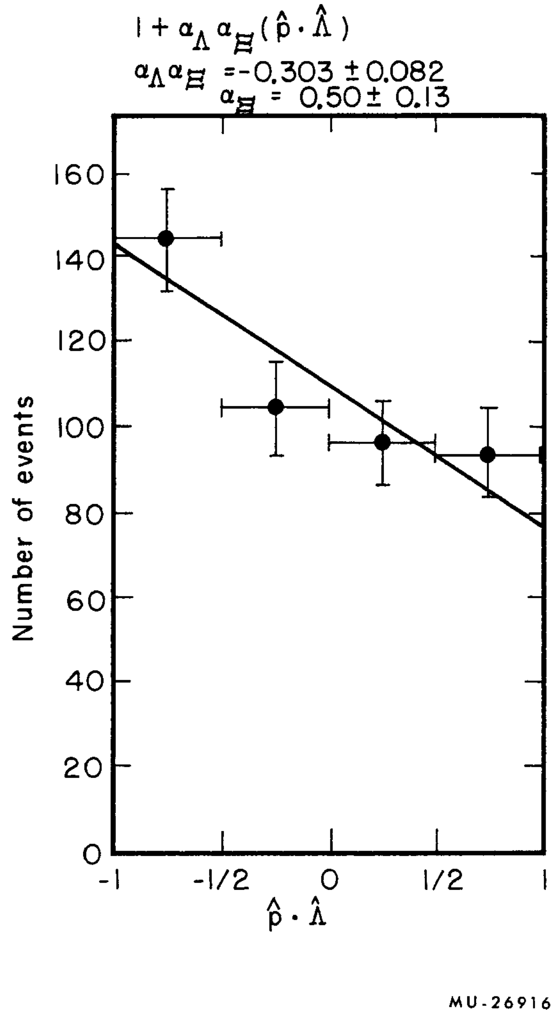
Fig. 4A. The same experimental comparison is made as in figure 3A, except for the γ_Ξ negative solution.

Fig. 4B. The same experimental comparison is made as in figure 3B, except for the γ_Ξ negative solution.



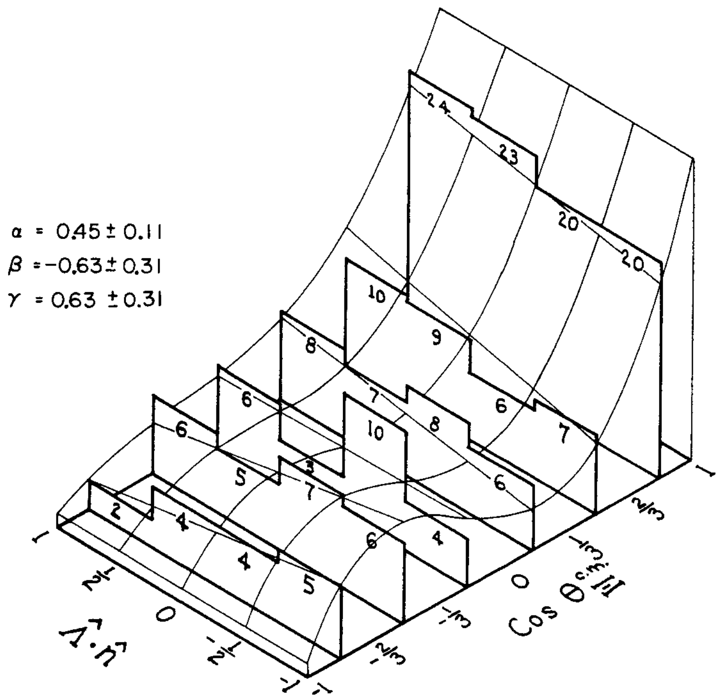
K⁻ + p → Ξ⁻ + K⁺
Production angular distributions
1.2 GeV/c
33 events
1.3 GeV/c
56 events
1.4 GeV/c
47 events
1.51 GeV/c
207 events
1.6 GeV/c
41 events
S,P,D waves
S,P waves
Number of events
Cos θ c.m. Ξ
MUB-1107

Fig. 1



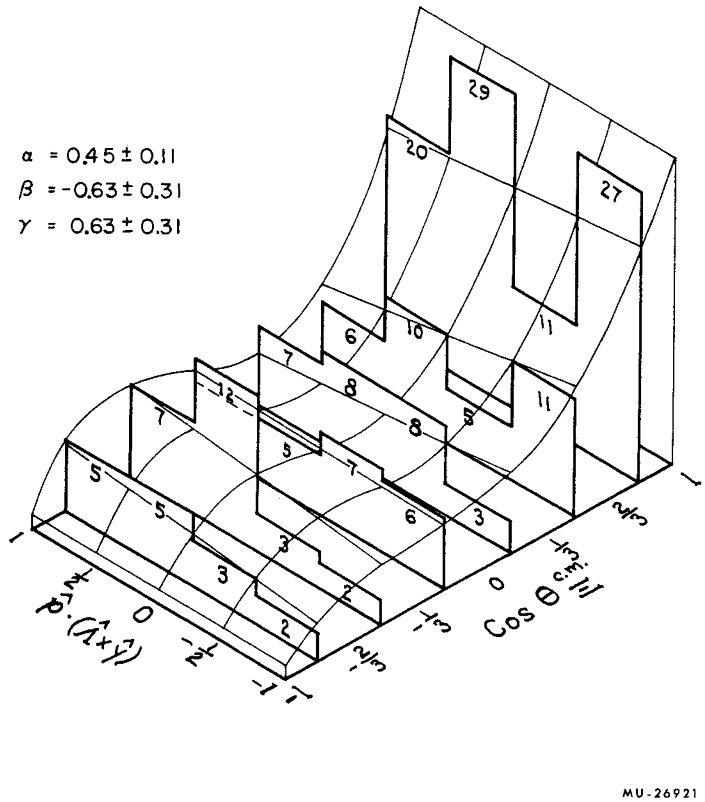
$1+\alpha_\Lambda \alpha_\Xi(\hat{p}\cdot\hat{\Lambda})$
$\alpha_\Lambda \alpha_\Xi = -0.303 \pm 0.082$
$\alpha_\Xi = 0.50 \pm 0.13$
Number of events
160
140
120
100
80
60
40
20
0
-1
-1/2
0
1/2
1
$\hat{p}\cdot\hat{\Lambda}$
MU-26916

Fig. 2



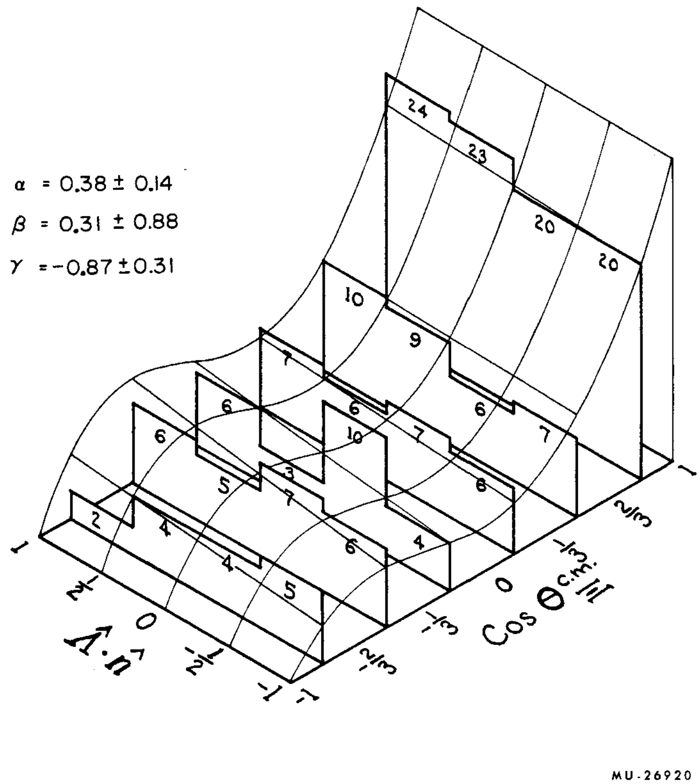
MU-26922

Fig. 3a-



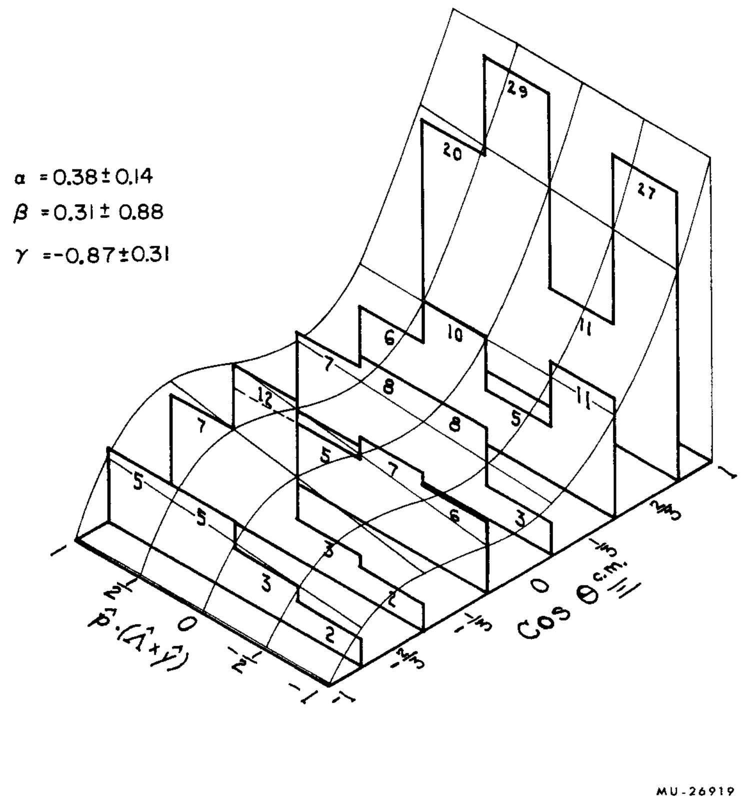
α = 0.45 ± 0.11
β = -0.63 ± 0.31
γ = 0.63 ± 0.31
29
20
27
6
10
11
7
8
5
11
7
12
8
5
7
5
6
3
5
3
3
2
2
Cos Θ c.m.
p̂·(Λ̂×Ŷ)
MU-26921

Fig. 3b.



α = 0.38 ± 0.14
β = 0.31 ± 0.88
γ = -0.87 ± 0.31
24
23
20
20
10
9
7
6
6
6
7
6
10
7
5
3
7
8
2
4
4
6
4
5
1
0
-1
Λ̂·n̂
Cos Θ c.m. Ξ
MU-26920

Fig. 4a.



α = 0.38 ± 0.14
β = 0.31 ± 0.88
γ = -0.87 ± 0.31
29
20
27
6
10
11
7
8
12
7
5
11
8
5
7
5
5
7
6
3
5
3
3
2
2
Cos Θ c.m.
MU-26919

Fig. 4b-