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Authors

Berge, J.P.
Bastien, P.
Dahl, O.
et al.

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Lawrence Radiation Laboratory and Department of Physics
University of California, Berkeley, California

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Alston et al.[1] have discovered an $I = 1$ π- Λ resonance with a mass of 1380 Mev and a half-width $\Gamma/2$ consistent with 32 Mev. They reported on 141 $\Lambda\pi^+\pi^-$ events made by 1150 Mev/c K^- mesons incident on the 15-in. Lawrence Radiation Laboratory hydrogen bubble chamber which produced the sequence

$$K^- + p \rightarrow Y_1^{*\pm} + \pi^{\mp} \qquad (1)$$

followed by a strong decay

$$Y_1^{*\pm} \rightarrow \Lambda + \pi^{\pm} + 130 \text{ Mev.} \qquad (2)$$

In the course of a continuing study of K^-p interactions, we have now explored the same reactions from Y_1^* threshold [P_K(lab) = 405 Mev/c] through P_K = 850 Mev/c. We report on ~500 $\Lambda\pi^+\pi^-$ and find $m(Y_1^*)$ = 1385 Mev and $\Gamma/2$ closer to 20 Mev; however we are still unable to distinguish between spins $J = 1/2$ and $J = 3/2$.

It is conventional to discuss Y^* data in terms of a simplified model in which they are produced and decay "isolated", that is, one neglects the interferences: (a) between Y_1^*'s and background $\Lambda\pi^+\pi^-$ produced in non-resonant partial waves, as well as (b) the influence of Bose statistics and final-state interactions on the $\pi\pi$ system.

Isolated Y_1^*'s will be produced in association with a pion of fixed center-of mass (c.m.) kinetic energy (spread, of course, by

$\pm \Gamma/2$). Thus in Fig. 1, which is Dalitz' representation of the $\Lambda \pi^+ \pi^-$ data at P_K(lab) = 850 Mev/c, Y_1^{*+} will fall in a horizontal band and Y_1^{*-} in a vertical band. That this model is poor is shown by the fact that conservation of parity requires that our isolated Y_1^* show no fore-aft asymmetry on strong decay, i.e. in the strong-decay distribution in the Y^* c.m. frame,

$$dn/d\Omega = 1 + a_1(\underline{\Lambda} \cdot \underline{Y}_1^*) + a_2(\underline{\Lambda} \cdot \underline{Y}_1^*)^2 + \ldots\ldots , \qquad (3)$$

the odd coefficients must be zero. However, our data show a concentration of backwards Λ. The asymmetry coefficients a_1, (assuming $a_2 = 0$) in Table I show that the "isolated" model is far from realistic, both for our new data and the older events at 1150 Mev/c(1). A major purpose of this Letter is to point out this difficulty.

In the following Letter,[2] Dalitz and Miller treat the reaction as a symmetrized three-body state which permits nonzero a_1. However some of the features of the isolated model are still discernable, for example the extra population of the Y_1^* bands on the Dalitz plots. Therefore, in order to simplify the discussion, in our Letter we still refer to this "isolated" model.

The data to which the model may be most meaningfully applied are those at P_K = 850 Mev/c, where the Y_1^* bands do not overlap badly (see Fig. 1). (They cross in the middle of the Dalitz plot at about 700 Mev/c.) Figure 2 is an experimental histogram of the Y_1^* mass. The individual uncertainty in each mass measurements is typically ±(3 to 5) Mev. If we fit the histogram with an s-wave resonance curve of the form $dn/dm \propto [(m - 1385)^2 + (\Gamma/2)^2]^{-1}$ as indicated in Fig. 2, we find $\Gamma/2$ = 15 to 20 Mev (depending upon whether or not some background is subtracted). This experimental value is an agreement with the "$\bar{K}N$ bound state" prediction of $\Gamma/2$ = 18 Mev,[3] but it is also not too far from global symmetry's $\Gamma/2$ = 25 Mev (see below).

Figure 3 displays the excitation data for Y_1^{*+} and Y_1^{*-} and total $\Lambda \pi^+\pi^-$. Data at 1150 Mev/c are from Alston et al.[1] and at 300 and 400 Mev/c are combined from the present experiment and from Nordin.[4] The Y_1^* cross sections at 850 Mev/c can be obtained fairly unambiguously in the sense that the $\Lambda\pi^+\pi^-$ events of Fig. 1 can be interpreted as a flat background plus an extra population of Y_1^*'s at the bands. A background subtraction is also possible at 760 Mev/c. However at 620 Mev/c, the bands cover almost the whole ellipse, making it impossible to distinguish Y_1^* events from background. At 510 Mev/c, the bands no longer cover the middle of the ellipse, and we might expect any appreciable Y_1^* population to show up in the bands above background. In the Dalitz plot of the data for P_K = 510 Mev/c in Fig. 4, we actually find, however, a concentration of events near the center of the diagram, not in the bands. This result could be consistent with essentially no Y_1^* production (as suggested in Fig. 3) plus a nonresonant background of $\Lambda \pi^+\pi^-$ events tending to favor equal pion momenta (for reasons unknown), it is also conceivable and quantitatively sensible that there is indeed appreciable Y_1^* production with the Y_1^* and the production pion predominantly in a relative p state (or higher). This would tend to depopulate the ends of the ellipse where the production pion momenta would be low and produce the observed distribution of events. Therefore one cannot determine unambiguously from these data the cross section for Y_1^* production at P_K = 510 Mev/c.

Table II illustrates the apportioning of events between the various possible reactions.

The Y_1^* production angular distributions are isotropic within statistics for all our beam momenta. This would suggest that Y_1 production proceeds dominantly through a single $J = 1/2$ wave. However the $\Lambda \pi^+\pi^-$ cross section alone comes very close to $\pi \lambda^2/2$, and so other partial waves are probably present.

Next we discuss the Y_1^* spin. Global symmetry predicts a $\Lambda\pi$

resonance with spin $J = 3/2$.[5] On the other hand, the Dalitz-Tuan s-wave resonance in the K^-p system corresponds to a Y_1^* with $J = 1/2$, and a strong-decay via $S_{1/2}$ if the $K\Lambda$ parity is odd.[6] If our model of an isolated Y^* were correct the strong decay angular distribution of Eq. (3) should be fore-aft symmetric ($a_1 = 0$), and the presence of any polar-equatorial anisotropy ($a_2 \neq 0$) would be evidence for $J > 1/2$. We find instead $a_1 \neq 0$ but within statistics $a_2 = 0$ at all production angles. After looking for evidence for $a_2 \neq 0$ at any (or all) angles of Y^* production, we have confined our analysis to polar-produced Y^*'s where, as Adair has pointed out,[7] an isolated $J = 3/2$ particle must decay according to $1 + 3\,(\underline{\Lambda} \cdot \underline{K})^2$ (the unit vector $\underline{K}$ is along the K^- beam direction) while $J = 1/2$ must decay isotropically. The decay distribution for polar-produced Y^*'s ($|\underline{Y}^* \cdot \underline{K}| \geq 0.80$) is given in Fig. 5. We have used $\underline{\Lambda} \cdot \underline{Y}^*$ as a measure of the decay angle instead of $\underline{\Lambda} \cdot \underline{K}$ in order to display the fact that the Y^* are not isolated but tend to strong-decay with the Λ going backwards. (Essentially the same result is achieved for these polar events by choosing $+\,\underline{\Lambda} \cdot \underline{K}$ for forward-produced Y^*, and $-\underline{\Lambda} \cdot \underline{K}$ for backwards Y^*). These Adair events of Fig. 5 again fail to show any evidence for $1 + 3\,(\underline{\Lambda} \cdot \underline{Y}^*)^2$ superimposed on the asymmetry, which is linear in $(\underline{\Lambda} \cdot \underline{Y}^*)$. This statement applies individually to both charges of Y^* at each momentum and to the sum of all events. However, as is shown in the next Letter, one cannot conclude that $J = 1/2$ since examples are given where Bose-statistics can cause a Y^* with $J = 3/2$ to have a relatively isotropic angular distribution in the Adair analysis.

Next we discuss the branching ratio $Y_1^* \rightarrow \Sigma$ vs Λ. Global symmetry predicts definite ratios between the decay rate $\Gamma(N)$ of the 3/2, 3/2 pion-nucleon isobar ($N^* \rightarrow N + \pi$) and the equivalent rates of, for example, the three decay modes of Y_1^{*-}. These are $\Gamma(N)$: $\Gamma(\Sigma^0)$: $\Gamma(\Sigma^-)$:

$\Gamma(\Lambda) = p_N^3 : (1/6)\, p_{\Sigma^0}^3 : (1/6)\, p_{\Sigma^-}^3 : (4/6)\, p_\Lambda^3$. For $p_N = 230$ Mev/c, $p_\Sigma = 127$, $p_\Lambda = 207$, $(p_\Lambda/p_\Sigma)^3 = 1/4$, the relative rates are predicted to be 1.37: 1/24: 1/24: 2/3. The half-width $\Gamma/2\,(N)$ is known to be 45 Mev; so global symmetry predicts a Y_1^* half-width $\Gamma/2 = 1/2[\Gamma(\Sigma^0) + \Gamma(\Sigma^-) + \Gamma(\Lambda)]$ of 24.7 Mev, and a branching ratio $\Gamma(\Sigma^0)/\Gamma(\Lambda) = 1/16$. (As already mentioned, our observed $\Gamma/2$ is 15 to 20 Mev, but the statistics are sufficiently poor and the effects of Bose-Statistics sufficiently great that $\Gamma/2 = 25$ Mev cannot be ruled out). The Dalitz-Tuan resonance is expected to give values of $\Gamma(\Sigma^0)/\Gamma(\Lambda)$ ranging from $\gtrsim 12\%$ (if the $K\Lambda$ and $K\Sigma$ parities are both odd) down to 6% (if $K\Lambda$ odd but $K\Sigma$ even).[3] The data for the most easily measured ratio, $\Gamma(\Sigma^0)/\Gamma(\Lambda)$, are given in Table III. The "realistic" upper limits on the ratios are obtained by making a background subtraction; the "maximum possible" upper limits come from counting every $\Sigma^0 \pi^+ \pi^-$ event with an effective $\Sigma^0\pi$ mass falling within 30 Mev of the Y_1^* mass of 1385 Mev.

The observed limits on the branching ratios are consistent with the predictions of global symmetry and not necessarily inconsistent with those of the Dalitz-Tuan resonance.

The $\underline{Y^{*-}\text{ polarization}}$ (Table IV) seems to be large at 850 Mev/c and, by comparison, surprisingly small at 760 Mev/c. This could be a statistical fluctuation, or may be connected with the fact that the Σ production channels also show a rapid variation with energy in this region.[8]

Since no strong evidence for Y^* spin $J = 3/2$ has yet been found either at Berkeley or elsewhere[9, 10], it is intriguing to assume $J = 1/2$ and to try to distinguish between $S_{1/2}$ and $P_{1/2}$ Y^* strong decay.

We use about 60 polarized Y^{*-} at 850 Mev/c (assuming that the polarization is not a statistical fluctuation). In addition to the normal $\underline{n}$ to the production plane, it is convenient to define another unit vector $\underline{m} = 2(\underline{n}\cdot\underline{\Lambda}) - \underline{n}$. This vector $\underline{m}$ lies in the plane of $\underline{n}$ and $\underline{\Lambda}$ (the direction of flight of the Λ), and if $\underline{\Lambda}$ makes an angle θ with $\underline{n}$, $\underline{m}$ makes an angle 2θ.[9] We write P_n for the measured Λ polarization along $\underline{n}$ and, similarly, P_m along $\underline{m}$. If the Y^* polarization is $\overline{P}$, then for strong decay via $S_{1/2}$, one can show

$$P_n = \overline{P},\ P_m = -\overline{P}/3,\ P_m/P_n = -1/3. \tag{5a}$$

For $P_{1/2}$ decay the roles of $\underline{n}$ and $\underline{m}$ are interchanged; i.e. the Λ has its maximum polarization along $\underline{m}$, and we have

$$P_n = -\overline{P}/3,\ P_m = \overline{P},\ P_m/P_n = -3. \tag{5b}$$

We find $P_n = (-56 \pm 20)\%$, $P_m = (+33 \pm 25)\%$ and $P_m/P_n = 0.6$. It is not meaningful to state statistical errors on a calculated ratio like P_m/P_n when the fractional standard deviations are large. Instead we apply the χ^2 test; the average value of χ^2 should be 1.0. For the $S_{1/2}$ hypothesis, we find $\chi_S^2 = 0.3$ (high probability), but for $P_{1/2}$, $\chi_P^2 = 4.5$ (probability $\approx 3\%$). Martin et al.[9] also report $P_n = -0.38 \pm 0.25$ and $P_m = 0.19 \pm 0.25$, which yield $\chi_S^2 = 0$, $\chi_P^2 = 1$. Thus if it were established (a) that Y^* is the Dalitz-Tuan resonance of a $K + p$ in an $S_{1/2}$ bound state and (b) that Eqs. (5) are not badly perturbed by interference phenomena, then our data would strongly suggest odd $K\Lambda$ parity.

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FOOTNOTES

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[†] National Academy of Sciences Fellow.

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Table I. Coefficient a_1(%) in Y_1^* strong-decay angular distribution.

P_KLab	Y_1^{*+}	Y_1^{*-}
760	-24 ± 20	-16 ± 20
850	-92 ± 26	-24 ± 24
1150	-70 ± 26	- 2 ± 20

Table II. Numbers and cross sections for V and two-prong events. Numbers in parentheses are cross sections in millibarns.

P_K(Mev/c)	$\Lambda\pi^+\pi^-$			$\Sigma^0\pi^+\pi^-$	$\Lambda\pi^+\pi^-\pi^0$	$\bar{K}^0 p\pi^-$	Total
	Y_1^{*-}	Y_1^{*+}	Three-body				
510	←	31(1.2±.3)	→	4(0.2±.1)	0	0	36
620	←	54(1.8±.3)	→	10(0.3±.1)	0(0)	0(0)	64
760	121(1.2±.14)	122(1.2±.14)	56(0.6±.1)	55(0.6±.1)	20(0.2±.05)	2(0.03±.02)	376
850	56(0.9±.25)	62(1.0±.25)	67(1.0±.15)	39(0.6±.1)	7(0.1±.04)	3(0.03±.02	234

Table III. Upper limits on the branching ratios $\Gamma(\Sigma^0)/\Gamma(\Lambda)$ for Y_1^*.

P_K (Mev/c)	$\Gamma(\Sigma^0)/\Gamma(\Lambda)$ (reasonable upper limit, %)	$\Gamma(\Sigma^0)/\Gamma(\Lambda)$ (maximum possible upper limit, %)
760	3	20
850	5	10

Table IV. Y^* polarization (in %) for $|\underline{Y}^* \cdot \underline{K}| \leqslant 0.85$, assuming Λ decay asymmetry coefficient $\alpha = +1$, Up $\equiv \underline{Y}^* \times \underline{K}$

P_K (Mev/c)	P_{Y^*}, c.m. (Mev/c)	Polarization Y^{*-}	Polarization Y^{*+}
760	240	+11±21	-16±21
850	250	-56±20	+12±28

FIGURE LEGENDS

Fig. 1. Dalitz plot of $K^- + p \rightarrow \Lambda + \pi^+ + \pi^-$ for 185 events at P_K(lab) = 850 Mev/c. Note that within the Y_1^{*-} band, for example (i.e. for constant T_{π^+}), T_{π^-} is linear in $(\underline{\Lambda} \cdot \underline{Y}^{*-})$, where Λ is the unit vector along the Λ momentum in the Y^* rest frame ($\underline{\pi}^- = -\underline{\Lambda}$). Thus Λ's which are produced forward by the strong decay of the Y^{*-} ($Y^{*-} \rightarrow \pi^- + \Lambda$) fall at the lower edge of the ellipse, and vice versa. Point A corresponds to maximum, and point B to zero, Λ kinetic energy.

Fig. 2. Experimental histogram of the Y_1^* mass, $m(Y_1^*)$, at P_K(lab) = 850 Mev/c. To each event plotted in Fig. 1 these corresponds two effective Y_1^* masses, $m(Y_1^{*+})$ and $m(Y_1^{*-})$; we choose as $m(Y_1^*)$ that which is closer to 1385 Mev. S-wave resonance curves of the form dn/dm $\propto [(m - 1385)^2 + (\Gamma/2)^2]^{-1}$ have been fitted to the data as indicated, with $\Gamma/2$ = 10, 15, and 20 Mev.

Fig. 3. Excitation data for total $\Lambda \pi^+ \pi^-$ production and its apportioning to Y^{*+} and Y^{*-}. The dashed curves show P_{Y^*}(c.m.) and $P^3_{Y^*}$(c.m.) as a function of P_K(lab) and are included for reference only. The line labeled $\pi \bar{\lambda}^2/2$ is the maximum reaction cross section for a single isotopic-spin partial wave with $J = 1/2$. The point plotted at P_K(lab) = 510 Mev/c represent an estimate of the cross section based on the assumption that the number of events actually within the "bands" (see Fig. 4) is the total number of Y_1^*'s produced and does not represent a unique interpretation of the data.

Fig. 4. Dalitz plot of $K^- + p \rightarrow \Lambda + \pi^+ + \pi^-$ for 31 events at P_K(lab) = 510 Mev/c.

Fig. 5. Adair analysis of 62 $Y^{*\pm}$ events at P_K = 760 and 850 Mev/c; $|\underline{Y}^* \cdot \underline{K}| \geq 0.80$.

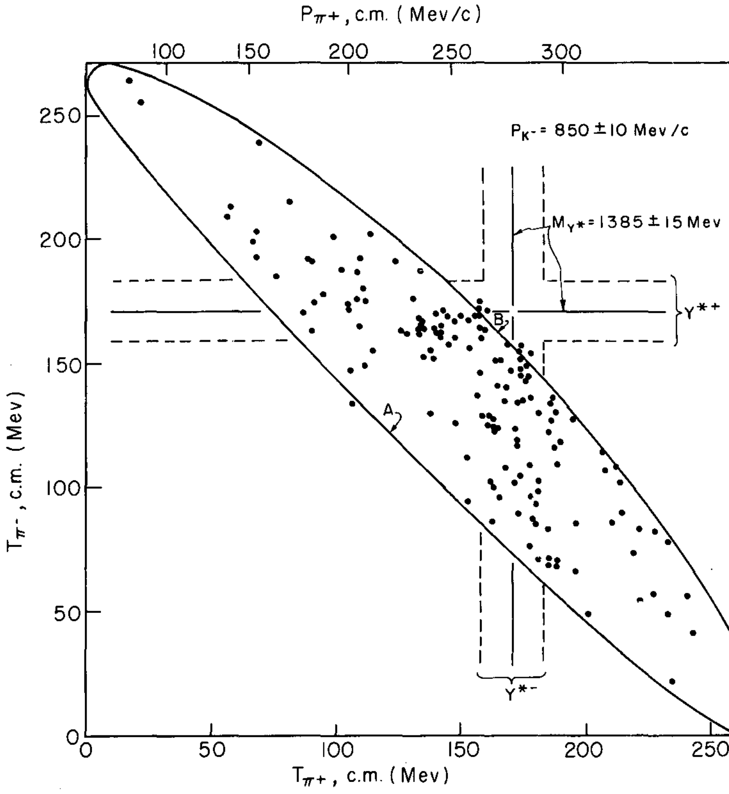

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Fig. 1

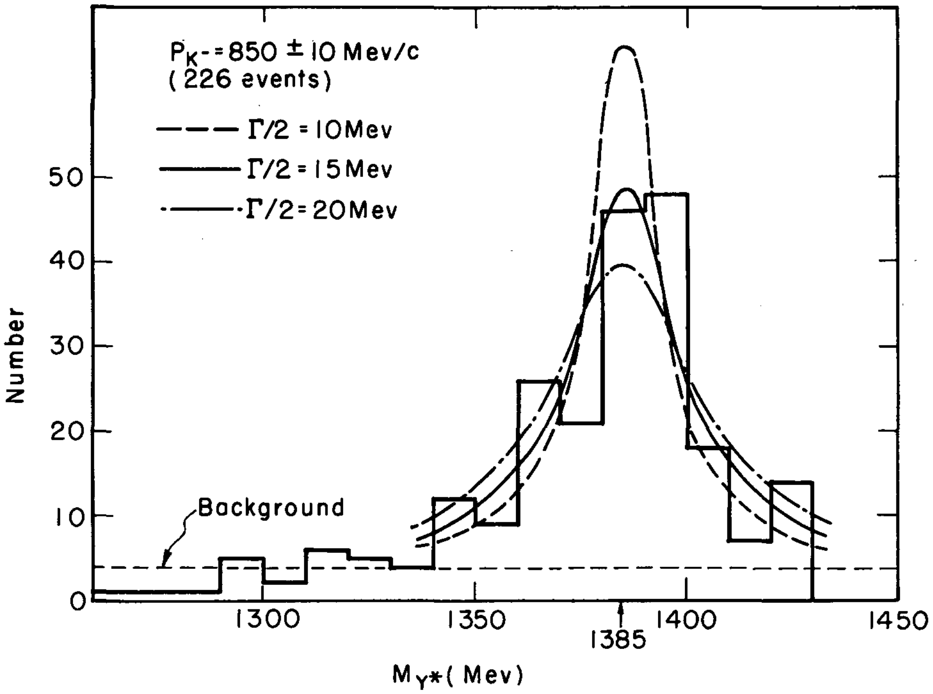

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Fig. 2

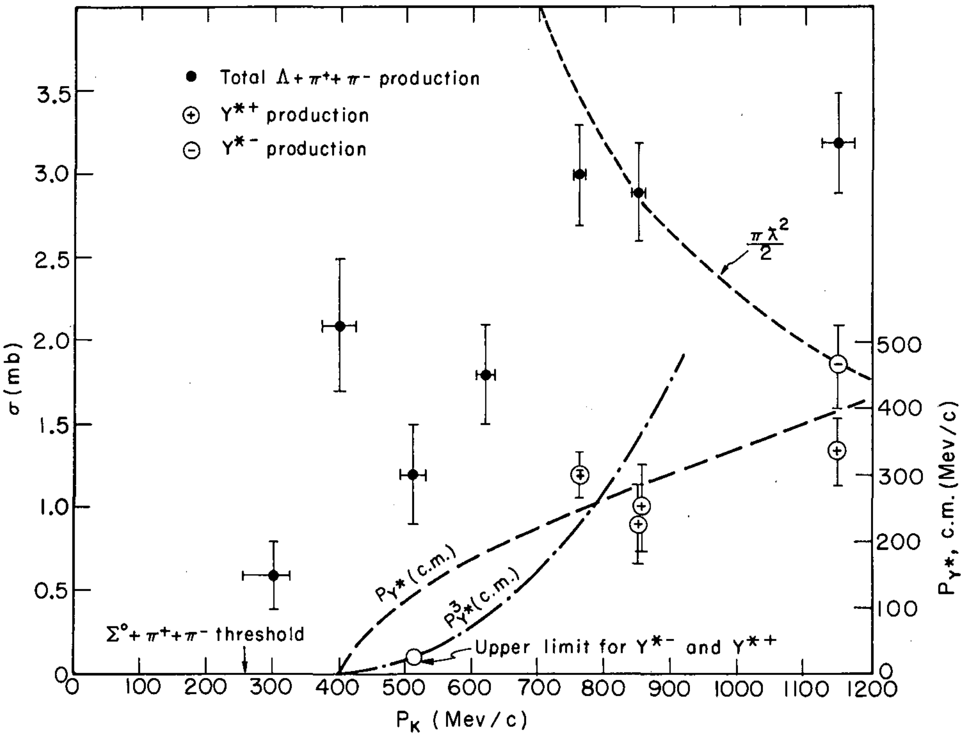

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Fig. 3

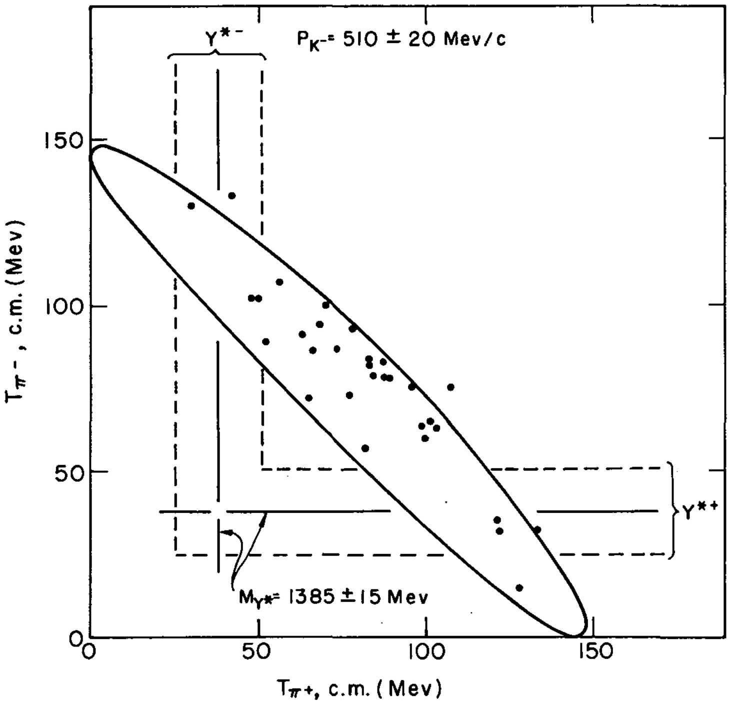

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Fig. 4

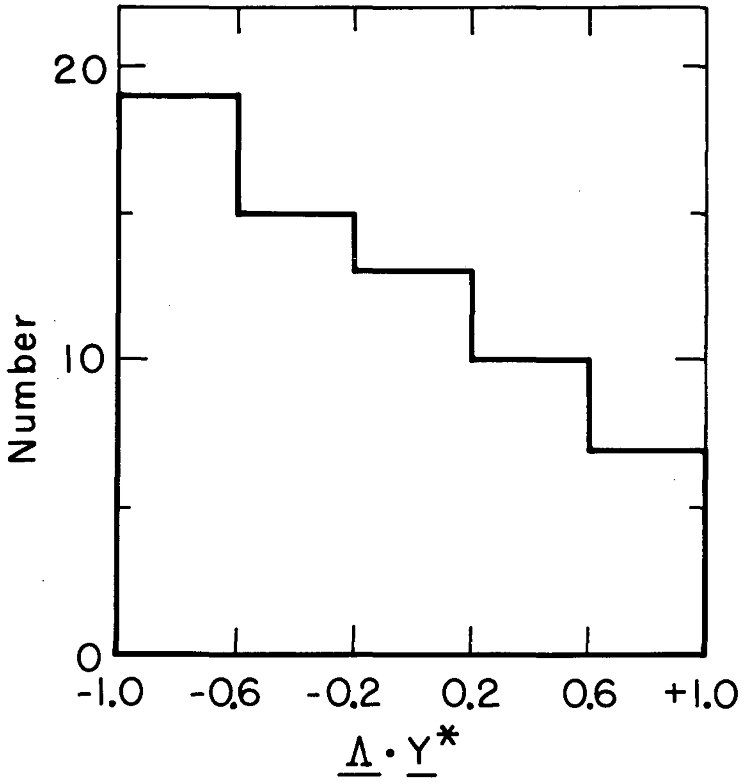

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Fig. 5