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SEARCH FOR LEPTONIC DECAYS OF THE SIGMA*

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As part of a continuing study of 8000 K absorptions in hydrogen[1] we have examined ~ 2000 Σ decays for evidence of leptonic modes.

In order to obtain events which were both unambiguous and accurately measurable, it was required that the length of the Σ track be greater than 0.5 mm, and the length of the decay-product track be greater than 5 cm and have a dip less than 60°. Of the total sample, 750 Σ^- and 250 $\Sigma^+ \rightarrow \pi^+ + n$ (effectively 500 Σ^+) satisfied the above criteria.

The search for leptonic decay modes was carried out by studying the (lab) momentum distribution of the Σ-decay products (shown in Fig. 1).[2] The vast majority of the events lies within the region ~ 160 to 224 Mev/c -- the kinematic limits of the normal Σ-decay modes, $\pi^\pm + n$. It is therefore clear that careful consideration must be given to the problem of momentum measurement before attempting to estimate the very small leptonic-mode contribution.

In order to investigate the effects of multiple and (unobservably) small-angle single scattering, we studied the momentum spectrum from the reaction $K^- + p \rightarrow \Sigma^- + \pi^+$ at rest, which yields a unique pion momentum of 174 Mev/c.

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†On leave from Syracuse University.

One should expect the measured distribution to be symmetrically distributed about 174 Mev/c (when plotted against curvature), the spread arising mostly from Coulomb scattering of the pion. Multiple scattering should produce a Gaussian distribution of half-width σ, which, for tracks of 15 cm mean length, 30° average dip, and $\beta = 0.8$, is $\sigma = \pm 11$ Mev/c. The systematics of single scattering leads one to expect that about 8% of the total number of events should have momenta $p_{\pi} \lessgtr 174 \pm 2\sigma$ Mev/c with a distribution $(174 - p_{\pi})^{-3} p_{\pi}$.[3] The calculated momentum spread due to the combined effects of multiple and single scattering is shown in the dashed curve of Fig. 2 (plotted against momentum and thus asymmetric). The measured momentum distribution $g\,(p_{\pi})$ of these selected primary pions is shown as the histogram of Fig. 2. On the basis of the excellent agreement between the observed and theoretical momentum spread, we conclude that our momentum errors are adequately understood.

It is convenient to use $g\,(p_{\pi})$ as the composite error function for momentum measurement. With appropriate adjustment to account for the difference in mean momentum, folding $g\,(p_{\pi})$ into the known c.m.-lab transformation[4] for the reaction $\Sigma^{\pm} \rightarrow \pi^{\pm} + n$, we obtain the dashed curve of Fig. 1. The agreement between the observed spectrum and that expected from the normal pion decay is excellent, indicating that the contribution of other decay modes is indeed small.

In the UFI theory of Feynman and Gell-Mann,[6] leptonic-mode rates are ~2 to 6%;[7] leptons should be emitted with a phase-space momentum spectrum (shown as the solid curve of Fig. 1). Since the leptonic spectrum extends well into the pionic spectrum, a detection cutoff must be chosen in order to obtain upper limits on the rate of leptonic decay. The choice of cutoff is somewhat arbitrary; we choose it at $p_{\pi} = 100$ Mev/c for several reasons. First, the background of single-scattered pions and pions from radiative decay[5] should be negligible below 100 Mev/c. Second, electrons with momenta below the cutoff should be distinguishable (with high efficiency) from pions of the same momentum, which have an ionization density of 3.5 times minimum.

We have seen no Σ-decay secondaries with momenta below 115 Mev/c. Since the fraction of phase space below the 100-Mev/c cutoff is 33%, we obtain an upper limit for the Σ^--electronic decay rate, for example, of $f\ (\Sigma^- \to e^- + n + \nu) \geq (750X.33)^{-1} = 0.4\%$. Branching fractions for the remaining modes[8] are given in the first column of Table I.

If the results of the present experiment are combined with the world total of published data, the rates shown in the second column of Table I are obtained.[9] In spite of the ambiguity inherent in the choice of detection cutoff it is clear from Table I that the observed rates are less than those expected on the basis of the UFI theory by about an order of magnitude. It has recently been shown that a similar discrepancy exists in Λ^0 leptonic decay.[10] While these results in no way detract from the enormous success of the Universal Fermi theory in nonstrange and kaon weak interactions, it is clear that a simple extension of the Fermi interaction with the inclusion of $\Sigma\bar{n}$ and $\bar{\Lambda}n$ terms cannot be considered an adequate model for the description of hyperon decays.

Table I

Upper limits to the branching fractions for leptonic decays

Leptonic mode	Maximum Rates (%)	
	This experiment	Total world data
$\Sigma^- \to e^- + n + \nu$	0.4	0.2
$\Sigma^+ \to e^+ + n + \nu$	0.6	0.4
$\Sigma^- \to \mu^- + n + \nu$	0.4	0.2
$\Sigma^+ \to \mu^+ + n + \nu$	0.5	0.3
$\Sigma^- \to \Lambda^0 + \substack{e^- \\ \mu^-} + \nu$	0.1	-
$\Sigma^+ \to \Lambda^0 + \substack{e^+ \\ \mu^+} + \nu$	0.2	-

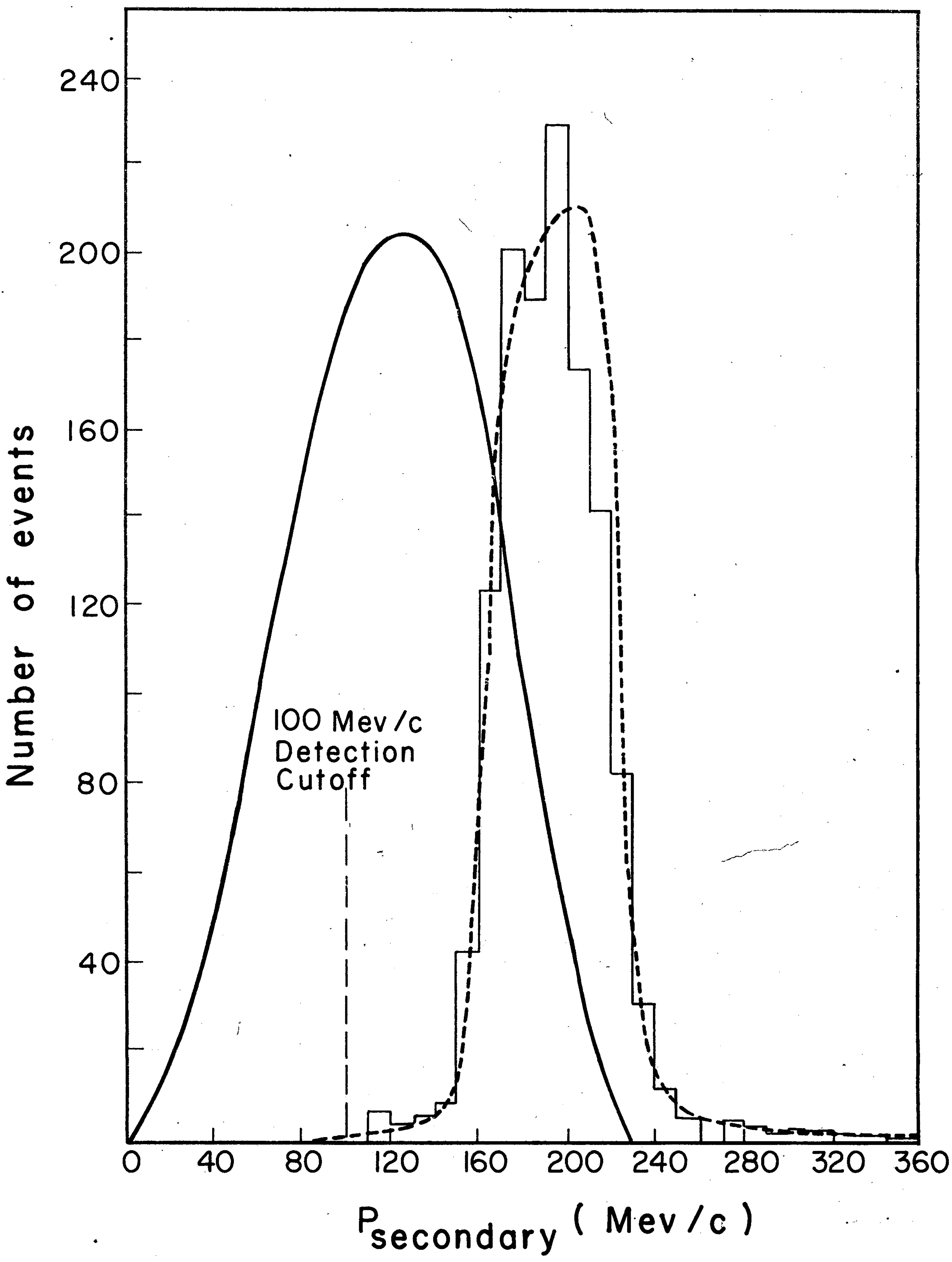
FOOTNOTES

1. Alvarez, Bradner, Gow, Rosenfeld, Solmitz, and Tripp, Nuovo cimento Serie X, 5, 1026 (1956).
2. The data shown in Fig. 1 have been corrected for a small in-flight contamination of ~ 3%.
3. Alvarez, Leitner, Rosenfeld, and Solmitz, Small-Angle Single Scattering, Berkeley Engineering Report 4310-03 (unpublished).
4. Leitner, Nordin, Rosenfeld, Solmitz, and Tripp, Angular Distributions in Σ Decay, Lawrence Radiation Laboratory Report UCRL-8737, May 1959. (unpublished)
5. S. Barshay and R. E. Behrends, Inner Bhremstrahlung in Hyperon Decays, Brookhaven report BNL-3956, Dec. 1958.
6. R. P. Feynman and M. Gell-Mann, Phys. Rev. 109, 193 (1958).
7. In the original presentation of reference 6, the Σ^+ leptonic decay is absolutely forbidden. However, if the $\Delta s = 1$ selection rule is relinquished, the Σ^+ leptonic decay is allowed and should occur with a relative frequency of ~ 3%.
8. Note that, to within a factor of ~2, these upper limits depend upon the choice of detection cutoff. For example, if the cutoff is taken at 135 Mev/c, about 2 standard deviations from the minimum momentum available to the pion from $\Sigma^{\pm} \to \pi^{\pm} + n$ decay, the upper limit on $\Sigma^- \to e^- + n + \nu$ decay becomes $1 \pm 4/750 \times 0.66 = 0.2\% \pm 1.0\%$.
9. The efficiency for the detection of the modes $\Sigma^{\pm} \to \Lambda^0 + e^{\pm} + \nu$ is 100% because of the low maximum electron momentum, leading to the lower rates shown in Table I. However, mere phase-space considerations indicate an expected rate of $\sim 10^{-4}$.

10. Crawford, Cresti, Good, Kalbfleisch, Stevenson, and Ticho, Phys. Rev. Lett. **1**, 377 (1958); Orear, Nordin, Rosenfeld, Solmitz, and Tripp, Phys. Rev. Lett. **1**, 380 (1958); F. Eisler et al., Nevis Report # 67, March 1958 (unpublished).

FIGURE CAPTIONS

1. Histogram of the $\Sigma^{\pm}$ decay secondaries. The solid curve is the phase-space spectrum of $\Sigma^{-} \rightarrow e^{-} + n + \nu$. The broken curve is the theoretical spectrum of $\Sigma^{\pm} \rightarrow \pi^{\pm} + n$, taking account of experimental resolution.
2. Histogram of the $\pi^{\pm}$ momentum distribution from $K^{-} + p \rightarrow \Sigma^{-} + \pi^{+}$. The dashed curve represents the calculated spread due to Coulomb scattering.



240
200
160
120
80
40
Number of events
100 Mev/c
Detection
Cutoff
0
40
80
120
160
200
240
280
320
360
P_secondary (Mev/c)

Fig 1

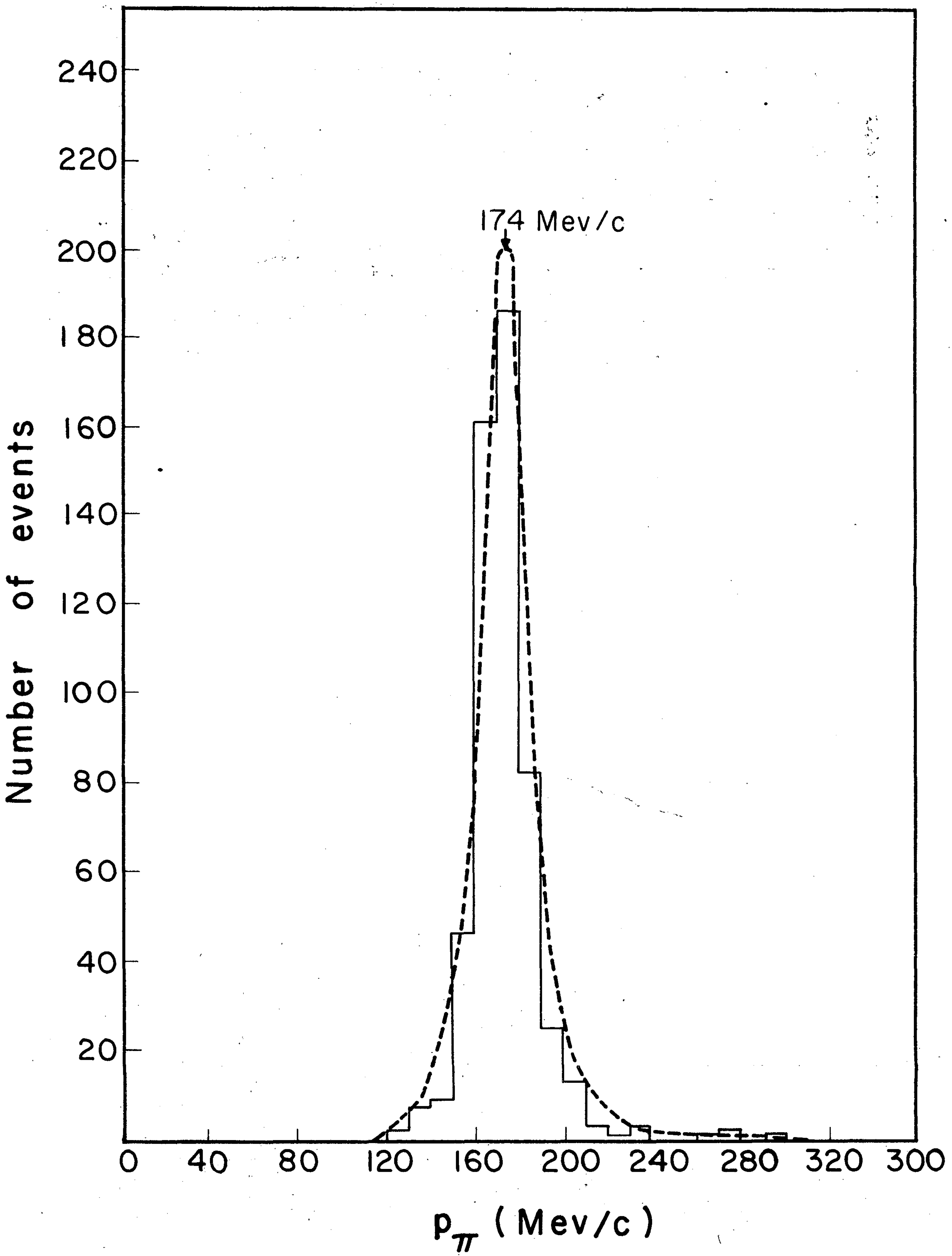

Number of events
240
220
200
180
160
140
120
100
80
60
40
20
174 Mev/c
0
40
80
120
160
200
240
280
320
300
p_π (Mev/c)

Fig 2