Paper contributed to the
Rochester APS Meeting,
August 30 - Sept. 2, 1971

LBL-4 c.2
Preprint

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AEC Contract No. W-7405-eng-48

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ABSTRACT

A double magnetic spectrometer at the Bevatron has been used to study the low neutrino energy ends of the $K_L^0 \to \pi\mu\nu$ ($K_{\mu 3}$) and $K_L^0 \to \pi e\nu$ (K_{e3}) decay spectra. The resolution of the apparatus and absolute invariant mass calibration were determined from $K_L^0 \to \pi^+\pi^-$ events accumulated with the $K_{\ell 3}$ events. A partial analysis yields neutrino mass upper limits (90% C.L.) of 1.0 MeV for the muon neutrino and 1.1 MeV for the electron neutrino.

The results of a preliminary study of the $K^0_{\ell 3}$ decay spectra and neutrino masses are reported here for two reasons. One is that the resulting muon neutrino mass limit is smaller than those previously published.[1] The other is to investigate the character of neutrinos produced in reactions involving a change in strangeness.

The data were accumulated during a search for the rare decays $K_L^0 \to \mu^+\mu^-$, e^+e^- and $\mu^\pm e^\mp$. The results of the search and a description of the apparatus have been published.[2] A schematic of the apparatus is shown in Figure 1. The high transverse momentum ($\gtrsim$ 200 MeV/c) required of each charged secondary enhanced the relative detection rate for $K_{\ell 3}$ events with low neutrino energy. The data sample used in this analysis represents about one third of the total accumulated with the evacuated decay volume.

The original invariant mass calculations were made with an effective length parameterization of the magnets. To achieve a better resolution and separate spurious events, all $K_{\ell 3}$ events with charged particle invariant masses above 490 MeV were re-evaluated after the trajectories had been integrated through the measured magnetic fields to improve the momentum resolution. One out of ten $K_{\pi\pi}$ events and one out of ten $K_{\ell 3}$ events in the invariant mass interval 475 to 490 MeV were subjected to the same procedure. The data reported here are from the re-evaluated sample.

As well as the usual data cuts to insure that the decays took place in the vacuum decay volume, two other requirements were used to reduce background. An event with a muon more than one range counter from its expected range was eliminated. Also, if a parent kaon when projected back from the vertex to the production target missed the target by more than 1 1/2", even when the missing neutrino momentum vector was assumed in the optimum direction, then the event was rejected.

Figure 2 shows the $K_{\pi\pi}$ invariant mass for the re-evaluated sample. This sample not only provides a worst-case measure of the invariant mass resolution of the apparatus (there are two pions which can decay in flight compared to one pion in the $K_{\ell 3}$ case) but it provides an absolute calibration for the invariant mass scale. That is, the fits to the $K_{\ell 3}$ invariant mass spectra do not depend on the measured value of the kaon's mass.

To compare the data with the expected distributions for massive neutrinos a Monte Carlo program was used to determine the detection efficiency of the apparatus. The results reported here are rather insensitive to the detection efficiency because the invariant mass intervals used in the fits are small; the detection efficiency for $K_{\ell 3}$ events with 10 MeV neutrino energy (center of mass) is about 75% of that for events at the zero neutrino energy end of the spectrum.

For these preliminary results, the $K_{\pi\pi}$ distribution has been used as the resolution function and has been folded in directly to the V-A predictions. Figure 3 shows the πe invariant mass spectrum from the K_{e3} events compared to the predicted curves for neutrino masses of 0 and 1.6 MeV. Except for the relative normalization there are no adjustable parameters. Figure 4 shows the χ^2 as a function of assumed neutrino mass; the 90% confidence level limit for the mass of the neutrino is 1.1 MeV. (The fits are somewhat better and the limit lower if a narrower $K_{\pi\pi}$ width is assumed.)

The $K_{\mu 3}$ events are known to have a background from the $K_{\pi\pi}$ events which have π decays upstream of the analyzing magnets. Figure 5 shows the $\pi\mu$ invariant mass distribution for well-identified $K_{\pi\pi}$ events with one of the secondaries purposely identified as a muon. The $K_{\pi\pi}$ events which are not so easily identified as $K_{\pi\pi}$ events should produce a broader $\pi\mu$ spectrum than that shown in the figure. To choose a $\pi\mu$ invariant mass interval which has a minimum of background and is suitable for neutrino mass fits we have compared the fits for different choices of invariant mass interval. Figure 6 shows the χ^2 per degree of freedom as a function of the lower limit of the fit interval. The upper limit is 498 MeV.

Confidence levels are good for intervals starting at or above 493 MeV. Figure 7 shows the $\pi\mu$ invariant mass spectrum along with the V-A predictions for neutrino masses of 0. and 1.6 MeV normalized to the interval 493 to 498 MeV. Figure 8 shows the χ^2 distribution for fits in this interval as a function of neutrino mass. The 90% confidence level limit for the mass of the muon neutrino is 1.0 MeV.

We have examined the fits for dependence on $K_{\ell 3}$ form factors and radiative corrections. There are no significant changes even for large changes in the form factors and radiative correction cut-off parameter.

More precise results are expected with the addition of the rest of the data and with the use of a constrained event fitting program which should improve the invariant mass resolution significantly.

FIGURE CAPTIONS

Fig. 1. Plan view of the apparatus. F and R are counter hodoscopes. H is a six counter array. T is a fast-timing counter. The spark chamber trigger required a charged particle on each side with transverse momentum greater than about 200 MeV/c.

Fig. 2. Invariant mass distribution for dipion events. The parent kaon is required to miss the production target by less than 1 1/2".

Fig. 3. Invariant mass for πe events compatible with K_{e3} decays. The solid curve is the V-A prediction for zero neutrino mass. The dashed curve corresponds to a neutrino mass of 1.6 MeV.

Fig. 4. K_{e3} χ^2 distribution as a function of assumed neutrino mass.

Fig. 5. $\pi\mu$ invariant mass distribution for purposely incorrectly identified $K_{\pi\pi}$ events.

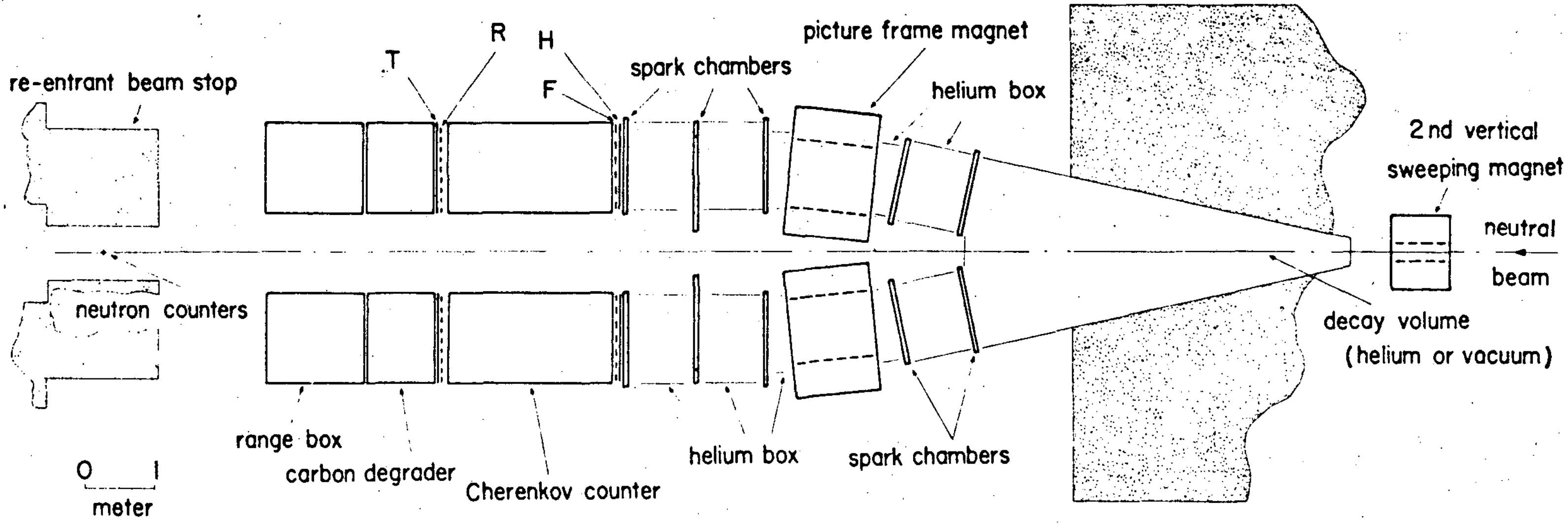
Fig. 6. Results of fits to the $\pi\mu$ invariant mass spectrum for different invariant mass intervals. The lower limit of the interval is the abscissa; the upper limit is always 493 MeV. The ordinate is the χ^2 per degree of freedom for the fit.

Fig. 7. $\pi\mu$ invariant mass spectrum for events compatible with $K_{\mu 3}$ events. The solid curve is the V-A prediction for zero neutrino mass. The dashed curve corresponds to a neutrino mass of 1.6 MeV.

Fig. 8. $K_{\mu 3}$ χ^2 distribution as a function of assumed neutrino mass.

FOOTNOTES

1. P.S.L. Booth, R.G. Johnson, E.G.H. Williams, and J. Wormald, Physics Letters 26B, 39 (1967).
2. R. Clark et al, Physical Review Letters 26, 1667, (1971).



XBL 702-315

Fig. 1

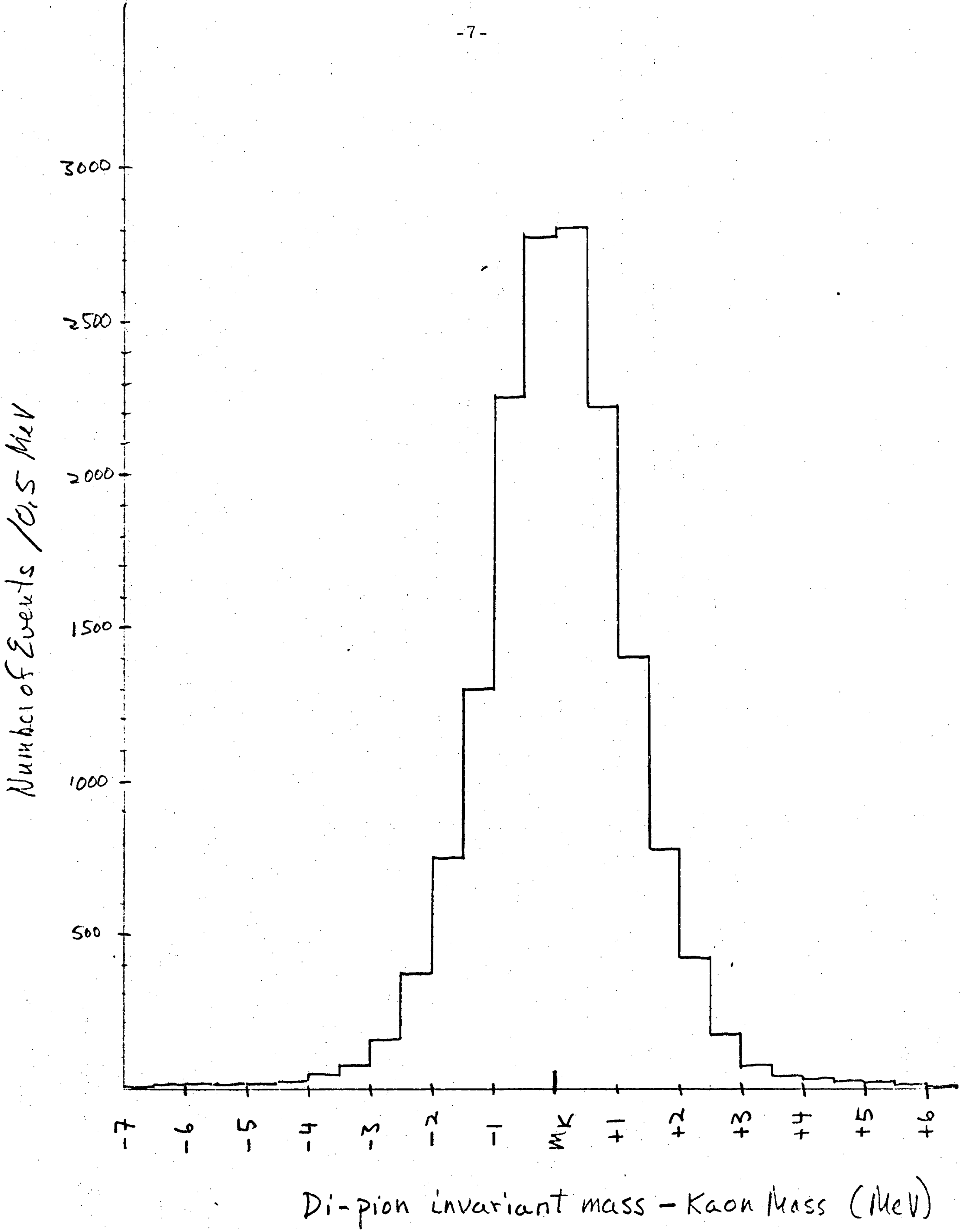

Number of Events /0.5 MeV
3000
2500
2000
1500
1000
500
-7
-6
-5
-4
-3
-2
-1
mK
+1
+2
+3
+4
+5
+6
Di-pion invariant mass - Kaon Mass (MeV)

Figure 2

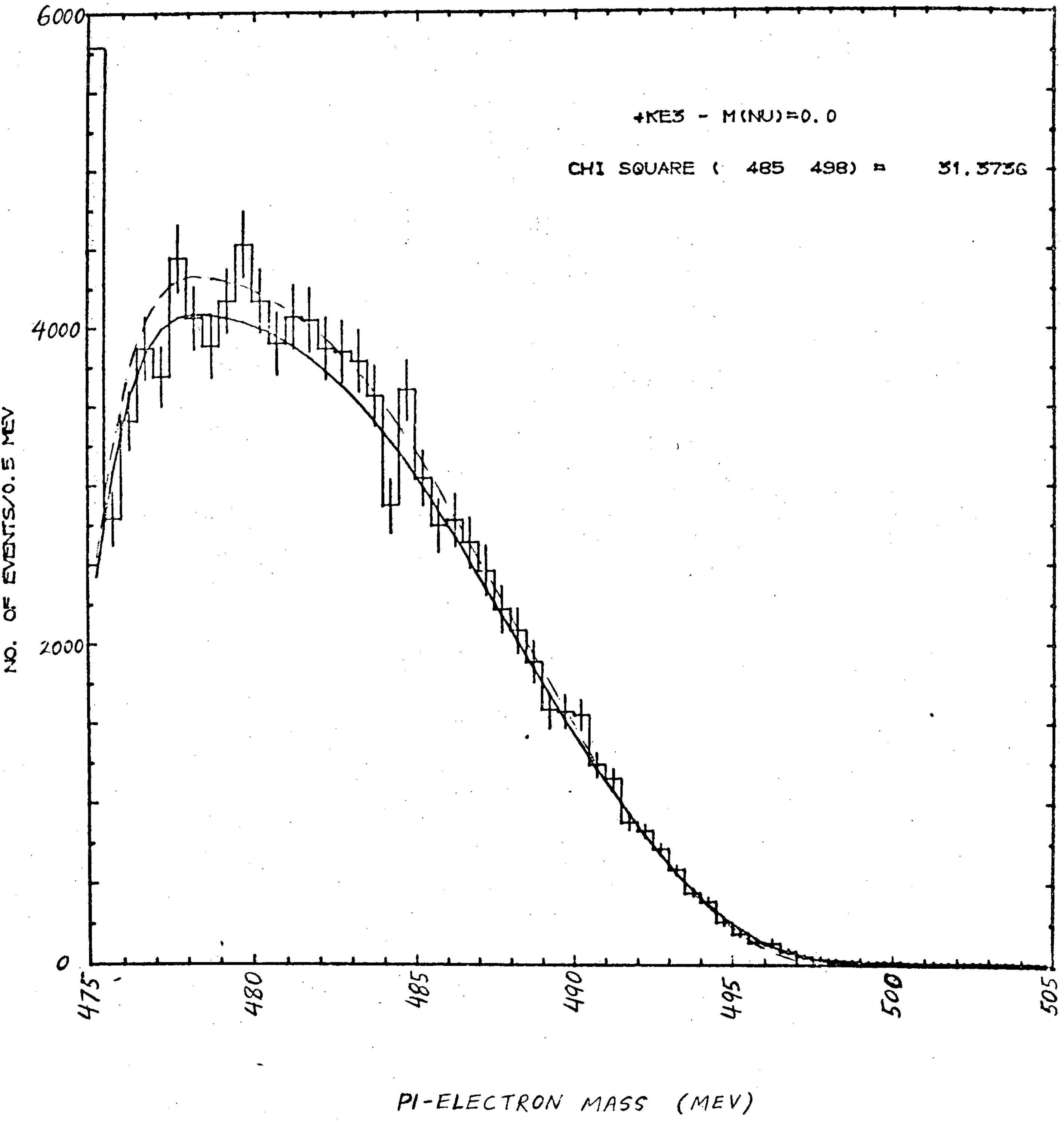

+KE3 - M(NU)=0.0
CHI SQUARE (485 498) = 31.5736
6000
4000
2000
0
NO. OF EVENTS/0.5 MEV
475
480
485
490
495
500
505
PI-ELECTRON MASS (MEV)

Figure 3

Figure 4

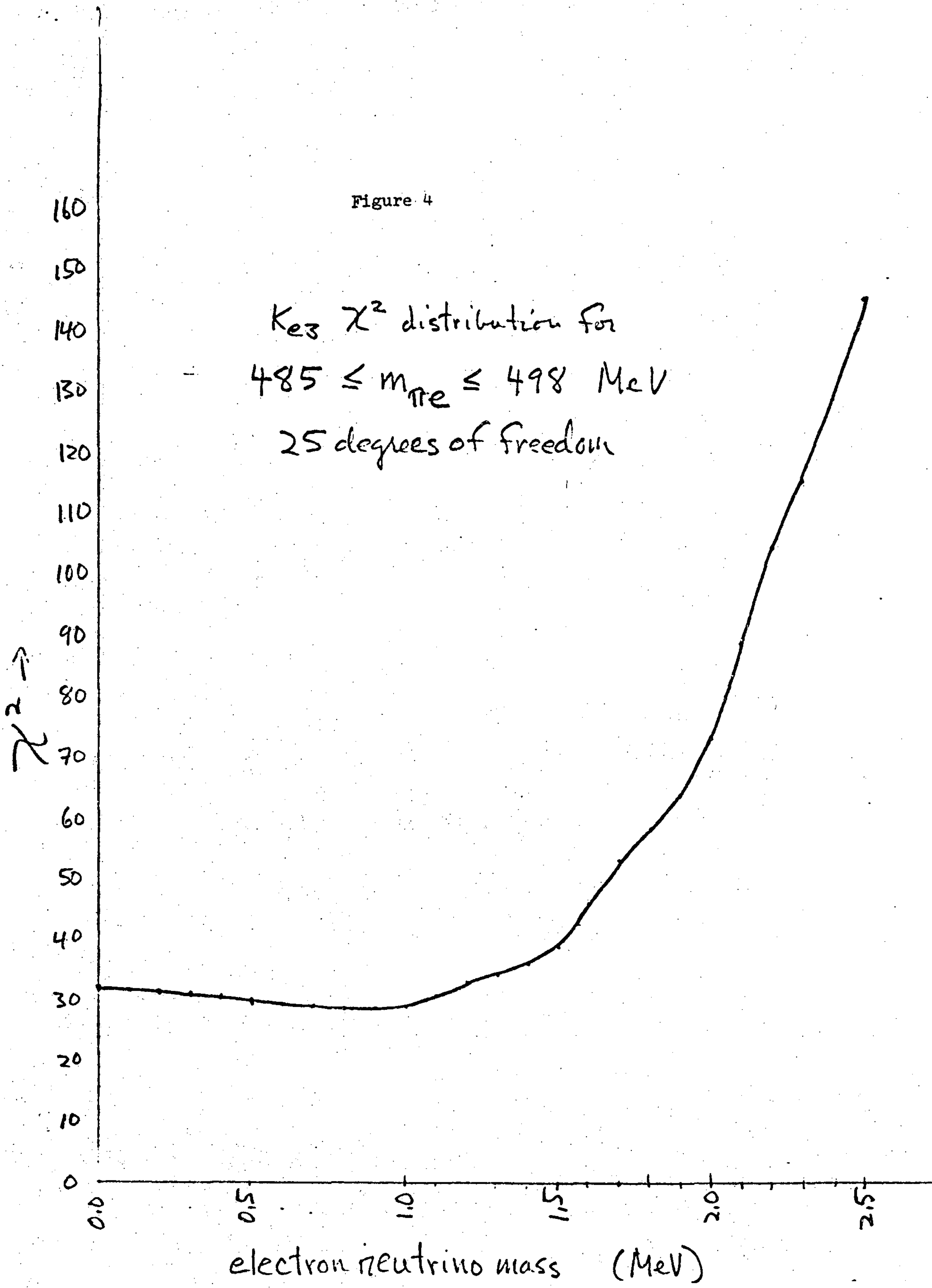
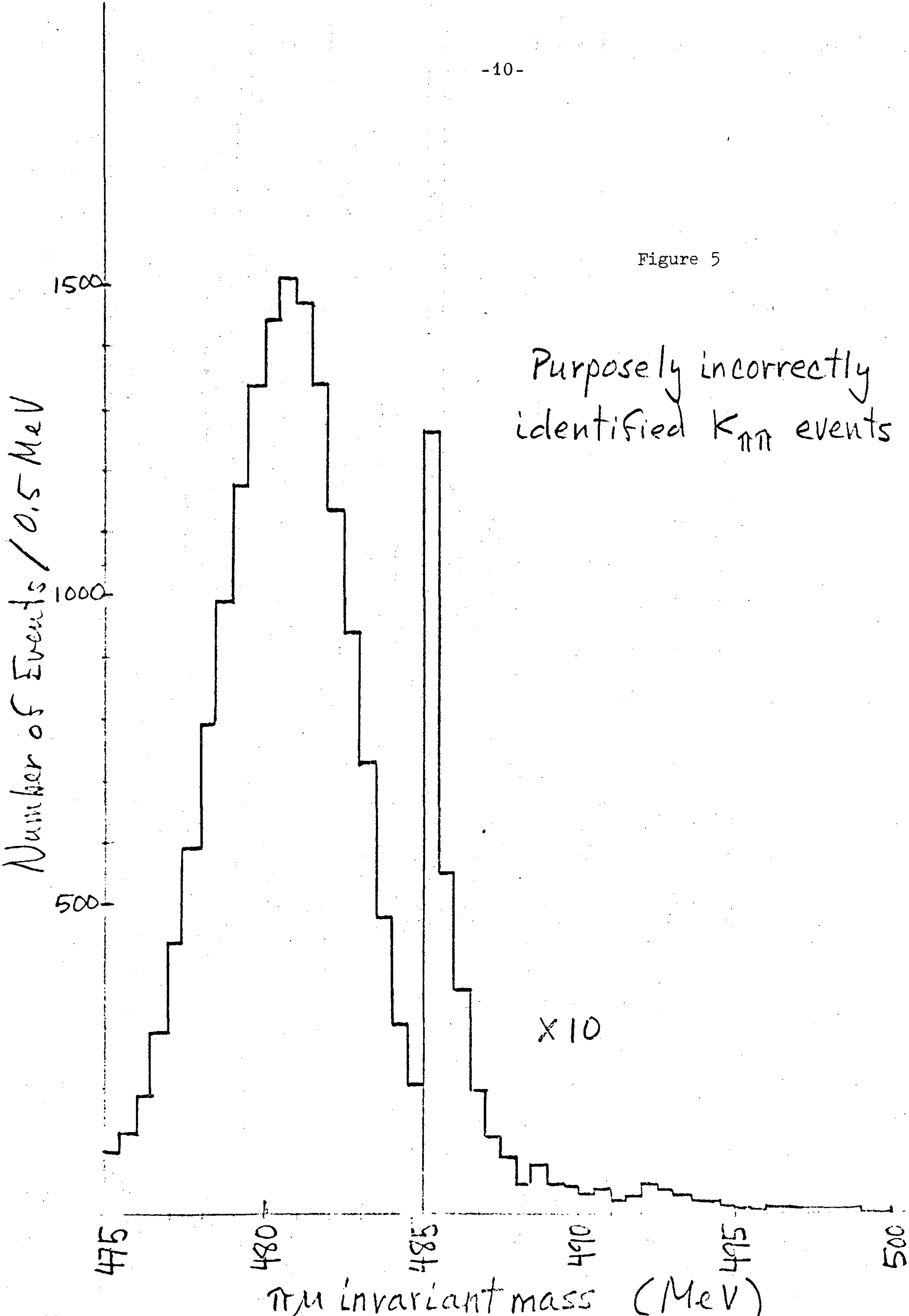

Ke3 χ² distribution for
485 ≤ mπe ≤ 498 MeV
25 degrees of freedom
χ² ↑
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0.0
0.5
1.0
1.5
2.0
2.5
electron neutrino mass (MeV)

Figure 5


Purposely incorrectly identified $K_{\pi\pi}$ events
X10
1500
1000
500
Number of Events / 0.5 MeV
475
480
485
490
495
500
πμ invariant mass (MeV)

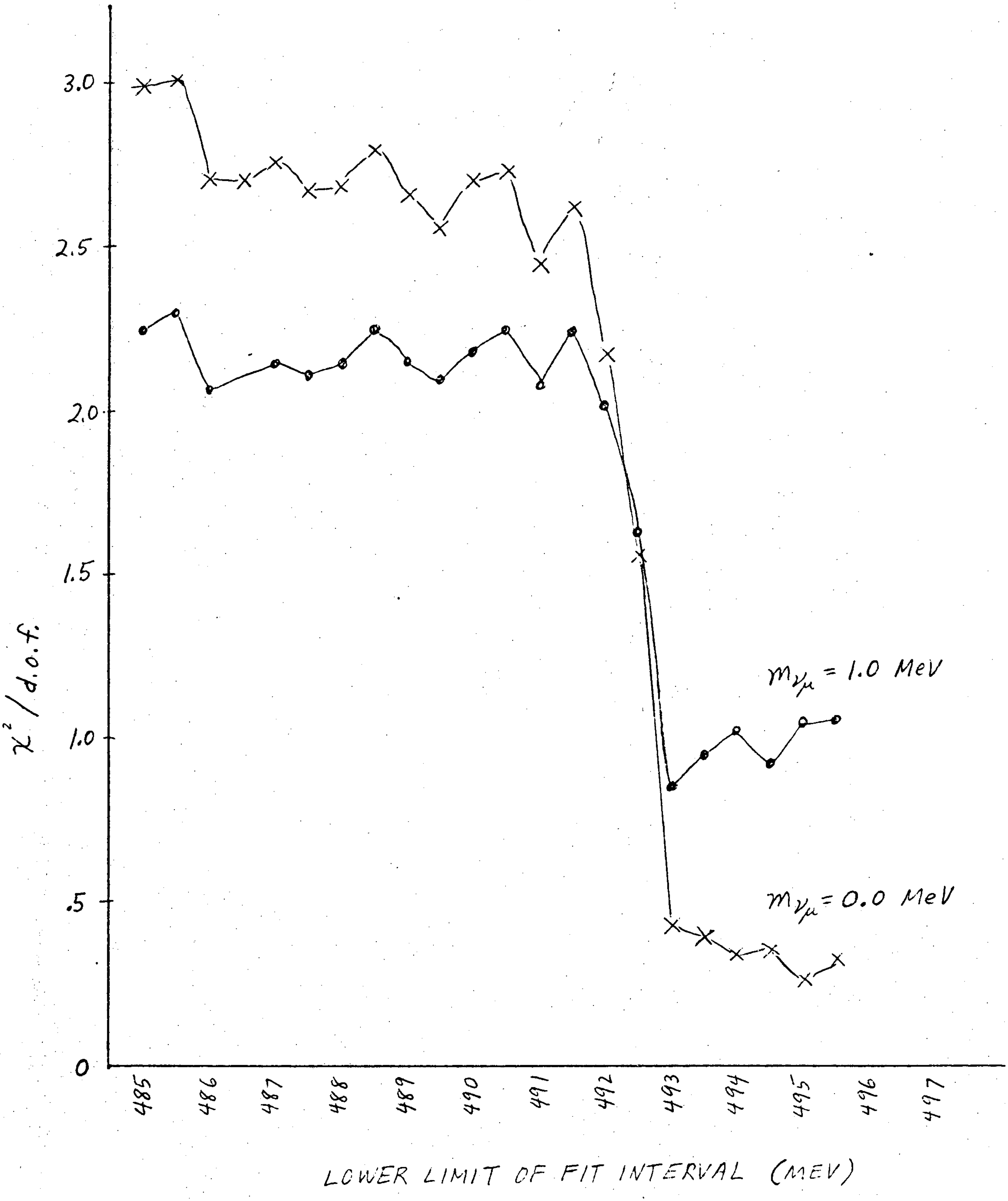

3.0
2.5
2.0
1.5
1.0
.5
0
χ^2/d.o.f.
485
486
487
488
489
490
491
492
493
494
495
496
497
LOWER LIMIT OF FIT INTERVAL (MEV)
m_{ν_μ} = 1.0 MeV
m_{ν_μ} = 0.0 MeV

Figure 6

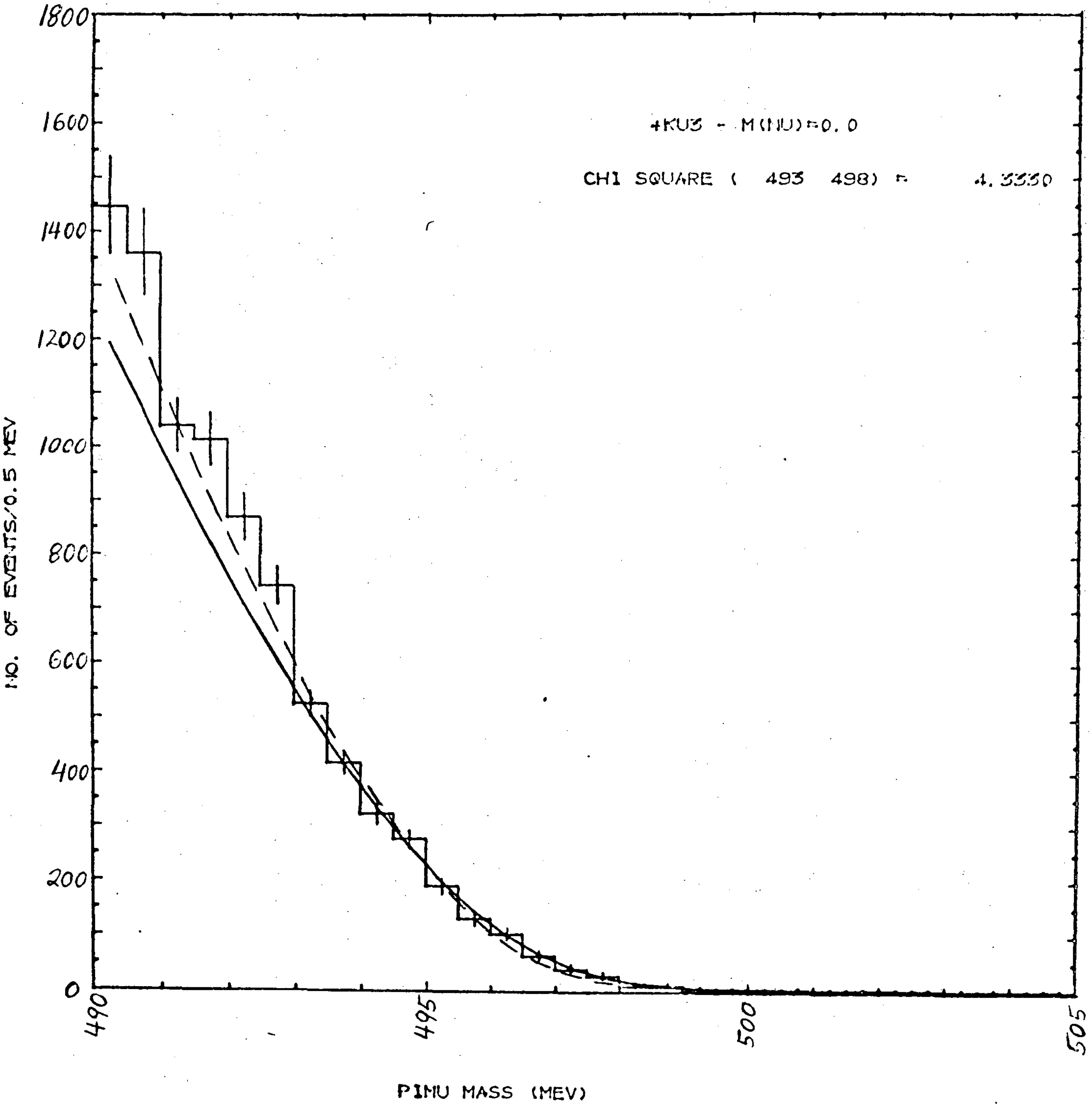
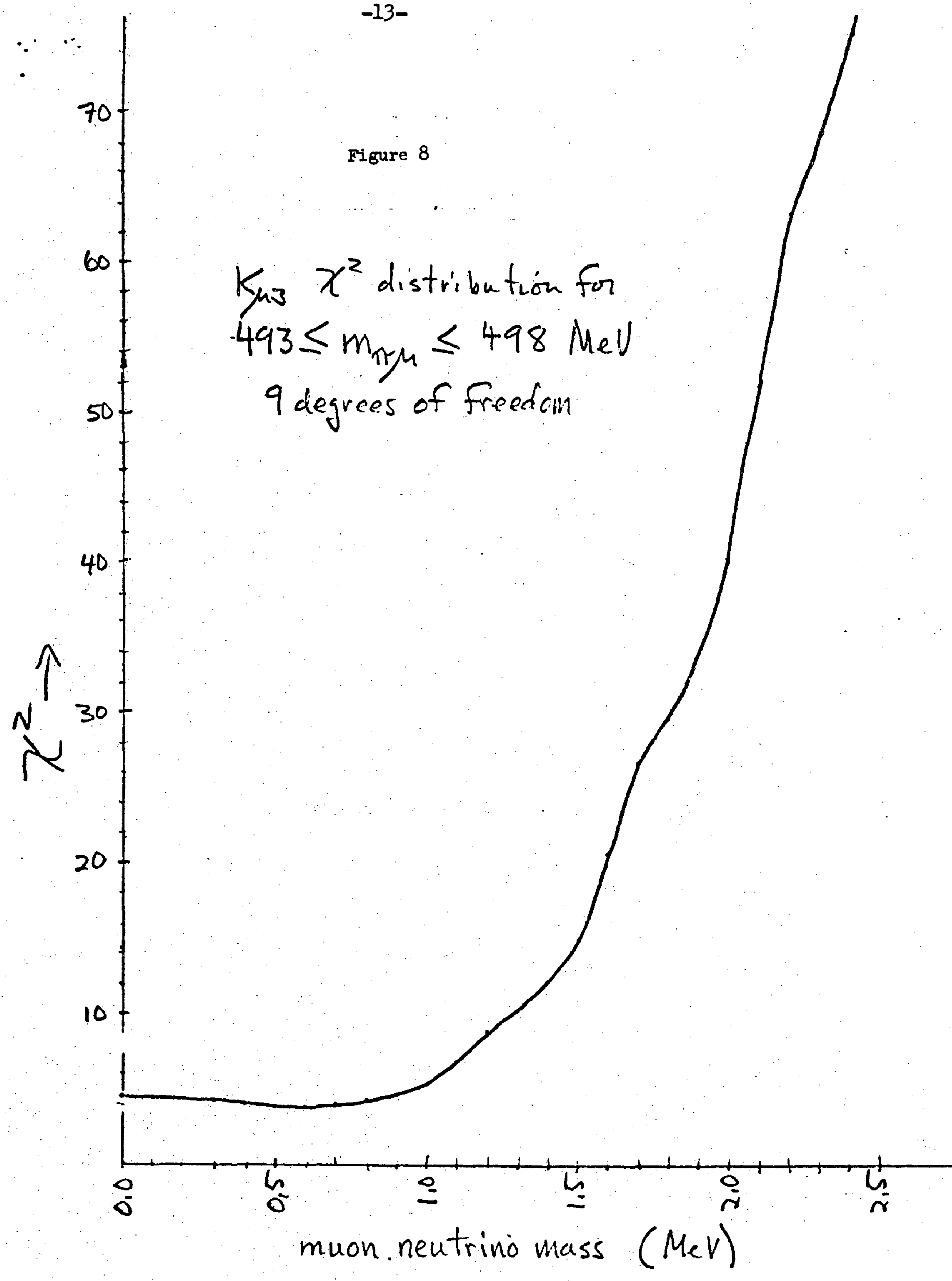

+KU3 - M(NU)=0.0
CHI SQUARE (493 498) = 4.3330
NO. OF EVENTS/0.5 MEV
1800
1600
1400
1200
1000
800
600
400
200
0
490
495
500
505
PIMU MASS (MEV)

Figure 7

Figure 8


$K_{\mu 3}$ χ^2 distribution for
$493 \leq m_{\pi\mu} \leq 498$ MeV
9 degrees of freedom
χ^2 →
70
60
50
40
30
20
10
0.0
0.5
1.0
1.5
2.0
2.5
muon neutrino mass (MeV)

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