Conf-780353--3

BNL-24536
OC 423

MASTER

LEPTON AND CHARM PRODUCTION IN THE 15 FOOT FNAL BUBBLE CHAMBER

A. M. Cnops, P. L. Connolly, S. A. Kahn, H. Kirk, M. J. Murtagh, R. B. Palmer, N. P. Samios, M. Tanaka
Brookhaven National Laboratory, Upton, NY

C. Baltay, D. Caroumbalis, H. French, M. Hibbs, R. Hilton, M. Kalelkar, W. Orance, E. Schmidt
Columbia University, NY, NY

Presented at the XIIIth Rencontre De Moriond Conference

Les Arcs, Bourg Saint Maurice, France

March 18-24, 1978

by

Robert B. Palmer

DISCLAIMER

LEPTON AND CHARM PRODUCTION IN THE 15 FOOT FNAL BUBBLE CHAMBER

Report by R. B. Palmer
Brookhaven National Laboratory, Upton, NY, USA

A. M. Cnops, P. L. Connolly, S. A. Kahn, H. Kirk, M. J. Murtagh, R. B. Palmer, N. P. Samios, M. Tanaka
Brookhaven National Laboratory, Upton, NY, USA

C. Baltay, D. Caroumbalis, H. French, M. Hibbs, R. Hilton, M. Kalelkar, W. Orance, E. Schmidt
Columbia University, NY, USA

ABSTRACT

The report is on ν interactions in the FNAL 15 foot bubble chamber filled with heavy neon. Inclusive production of π^+, π^-, K^o and Λ^o is shown. Limits are given on the production and hadronic decay of Λ_c. The rate of D^o production and decay to $K^o\pi^+\pi^-$ is reported. Events containing a μ^- and e^+ are observed and interpreted as leptonic decay of charm. Events with single e^+ or e^- are reported and found to be consistent with $\bar{\nu}_e$ and ν_e interactions.

Le rapport traite des interactions ν dans la chambre à bulle FNAL de 15 pieds remplie de néon lourd. On y montre la production inclusive de π^+, π^-, K^o et de Λ^o. Des limites sont attribuées à la production et à la désintegration hadronique de Λ_c. Le taux de production de D^o et de désintegration en $K^o\pi^+\pi^-$ y est rapporté. On observe les événements comportant un seul e^+ ou un e^- et on trouve qu'ils sont cohérents avec les interactions $\bar{\nu}_e$ et ν_e.

1. INTRODUCTION

The following report is on our experiment done at FNAL in the 15 foot bubble chamber filled with 64% (atomic) neon and 36% (atomic) hydrogen. The chamber was run in the FNAL two horn "wide band" neutrino beam whose energy distribution is shown in Figure 1. With this combination a charged current rate of about one event per two pictures was obtained, much higher than that obtainable with the quadruple triplet beam (again see Figure 1).

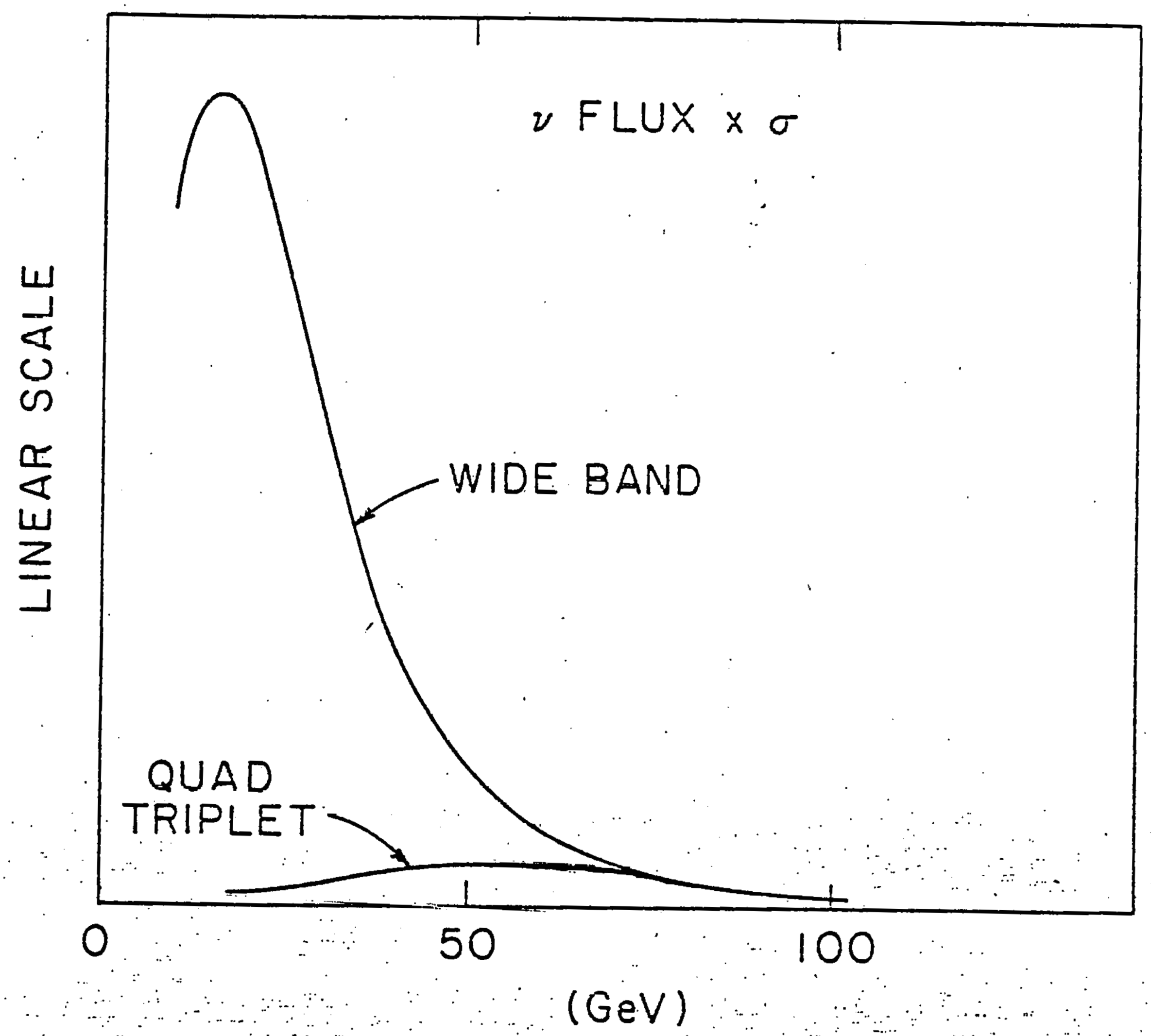

Figure 1. Energy distribution of flux times cross section, assuming cross section proportional to energy.

In addition, the use of neon provided good gamma and electron identification (the chamber is 3.6 meters diameter and the radiation length is 40 cm) and moderate hadron identification (the interaction length is 1.25 meter).

The following results were obtained from the analysis of 96,000 pictures containing 46,400 charged current events. All events containing a K^o, a Λ^o or an electron were measured (approximately 3,000 events). In addition a smaller sample of charged current events was measured without the above requirements. This report will cover data on inclusive production of π's, K's and Λ's and the search for hadronic decays of charmed particles. Events containing an e^+ or e^- will be analyzed in terms of contributions from charm decay, ν_e and $\bar{\nu}_e$ interactions and possible contributions from heavy leptons.

2. NON CHARMED HADRON PRODUCTION

For charged current events, Figure 2 shows the corrected $K^o + \bar{K}^o$ and $\Lambda + \Sigma^o$ production as a function of W_{vis} (the visible center of mass energy of all hadrons). The mean value of W_{vis} for this experiment was 3.3 GeV and the mean fractions of events with K^o's and Λ's/Σ's were 13.6 ± 1.5 and 5 ± .5%, respectively.

Figure 3, again for charged current events, shows the multiplicities of π^+, π^-, K^o and Λ/Σ^o as a function of Z, where Z is the corrected fraction of hadronic momentum carried by the particle in question. The correction is given by the formula:

$$Z = \frac{P_i}{E_{other} \times 1.4 + P_i} \quad (1)$$

where P_i is the momentum of the particle in question and E_{other}, the total hadronic energy excluding P_i. This correction is not exact and will somewhat distort the resulting distributions shown in Figure 3. Nevertheless, one may note the general feature that as $Z \to 1$ the production of π^-, K^o's and Λ's are all similar and all a factor of about 10 below that for π^+'s. This may reflect the fact that the $\pi^+(u\bar{d})$ can be formed with one ocean quark, the other coming from the fast valence quark leaving the initial interaction ($\nu + d \to \mu^- + u$). For the π^-, K^o and Λ two quarks have to come from ocean in each case. It should be noted, however, that these characteristics may arise simply from mass and charge conservation considerations and do not of themselves prove anything about leaving quarks.

3. HADRONIC DECAYS OF CHARM

A search was made for hadronic decays of the D and Λ_c charmed hadrons.

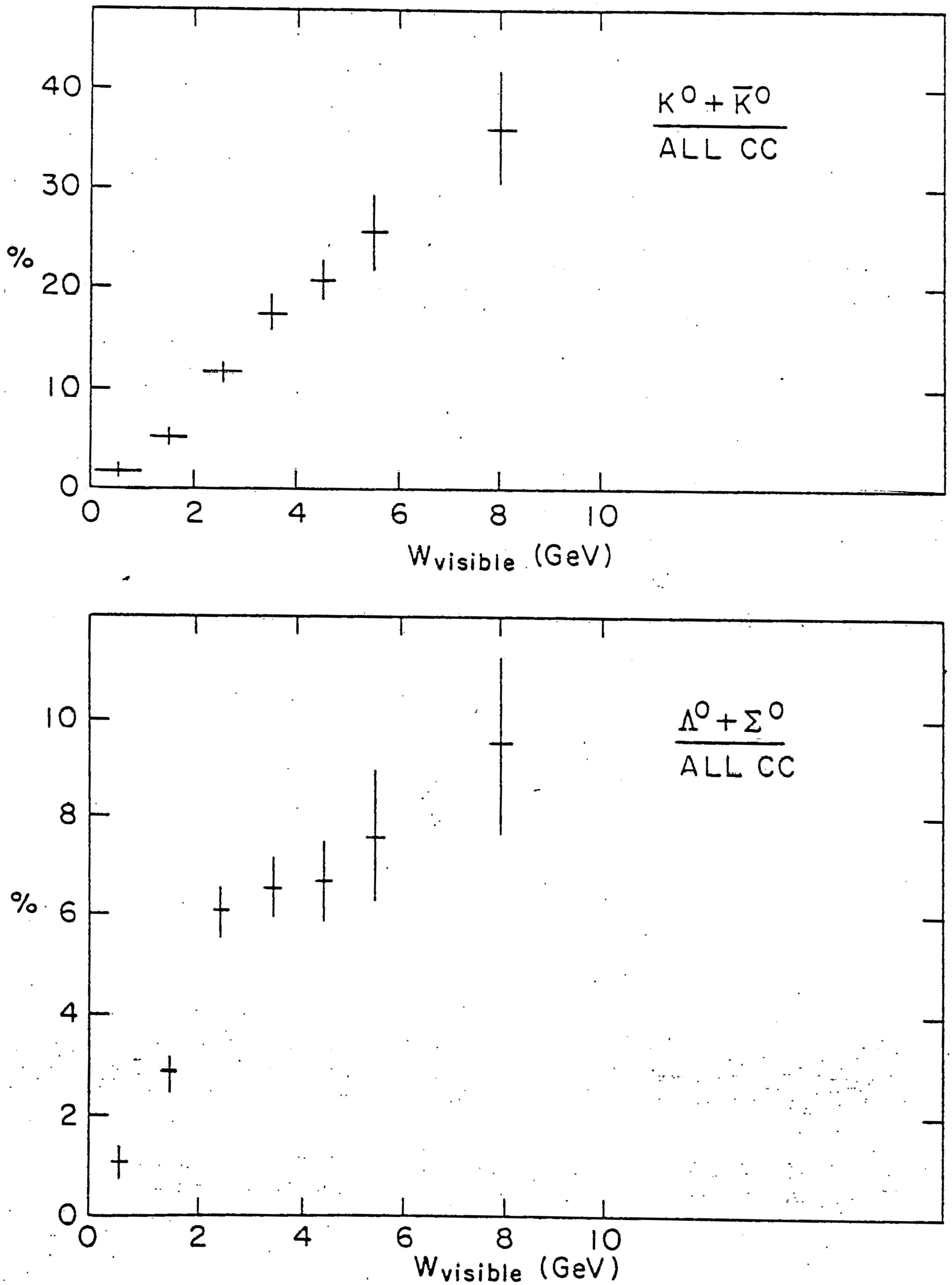

Figure 2. Multiplicities of strange particle production in charged current interactions versus the visible hadron energy for (a) K^0 and $\bar{K}^0$ and (b) Λ^0 and Σ^0.

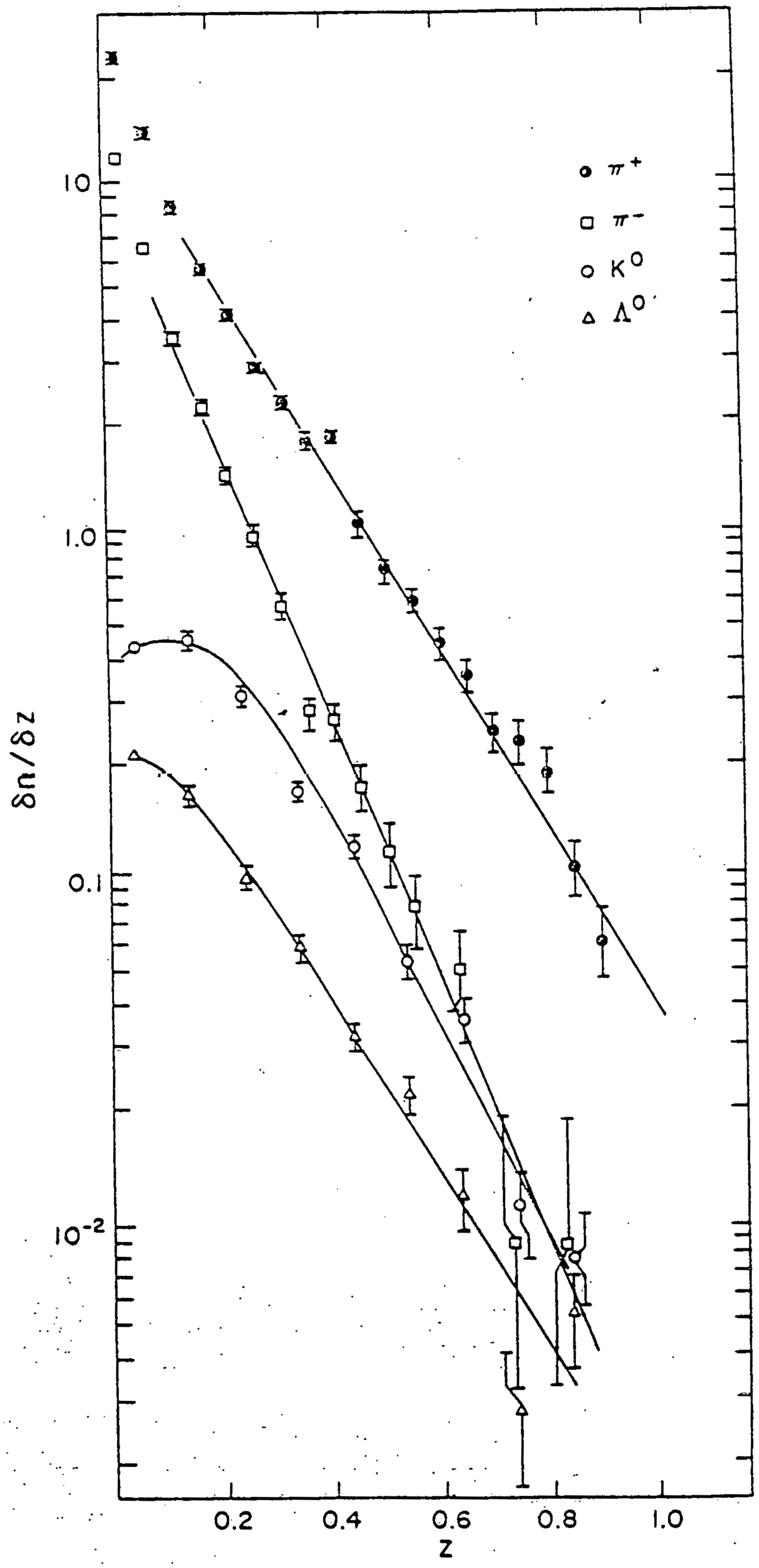

Figure 3. Multiplicities of particle production in charged current interactions versus Z the corrected fraction of the total hadron energy carried by the particle.

The modes studied were

$$\Lambda_c^+(2250) \rightarrow \Lambda\, \pi^+\pi^+\pi^- \quad (2)$$

$$\Lambda_c^+ \rightarrow \Lambda\, \pi^+ \quad (3)$$

$$D^+ \rightarrow K^o\pi^+ \quad (4)$$

$$D^o \rightarrow K^o\pi^+\pi^- \quad (5)$$

Plots of the observed effective mass distributions are shown in Figures 4 through 7. No signal is observed in reactions (2) and (4). A small signal is apparent in channel (3) but is not observed if a cut is made of helicity angle ($\text{Cos}\theta_H^* > -0.6$). This cut was chosen to remove the large background from events with a slow Λ and fast pion, and should have enhanced the signal to background ratio. The fact that this does not occur suggests that the observed enhancement is a fluctuation. From these results we obtain the following 90% confidence level limits for branching ratios times fraction of charged current production:

$$\Lambda_c \rightarrow \Lambda\, \pi^+\pi^+\pi^- \quad \leq .2\% \quad (6)$$

$$\Lambda_c \rightarrow \Lambda\, \pi^+ \quad \leq .1\%$$

$$D^+ \rightarrow K^o\pi^+ \quad \leq .2\%$$

In reaction (5) $D^+ \rightarrow K^o\pi^+\pi^-$ (Figures 7a and 7b) a clear signal is observed at the expected mass value. A fit using a gaussian on a polynomial background gave a signal of 64 ± 15 events, a mass of 1850 ± 15 MeV. The width was 23 MeV which is consistent with our resolution. This signal corresponds to a branching ratio times fraction of charged current events of 0.7 ± .2%.

Comparing this with the limit on D^+ production and using the SLAC branching ratios of 4 ± 1.3% for $D^o \rightarrow K^o\pi^+\pi$ and 1.5 ± .6% for $K^o\pi^+$ we obtain the ratio

$$\frac{\sigma(D^+ \text{ production})}{\sigma(D^o \text{ production})} = .5 \pm .4 \leq .76 \text{ (90\% CL)} \quad (7)$$

Using this sample of D^o's we have looked for evidence of D^*'s by plotting $D^o\pi^+$ and $D^o\pi^+\pi^-$ masses. No evidence of D^*'s were seen but an enhancement in the $D^o\pi^+\pi^-$ mass spectrum at 4.9 GeV is present (see Figure

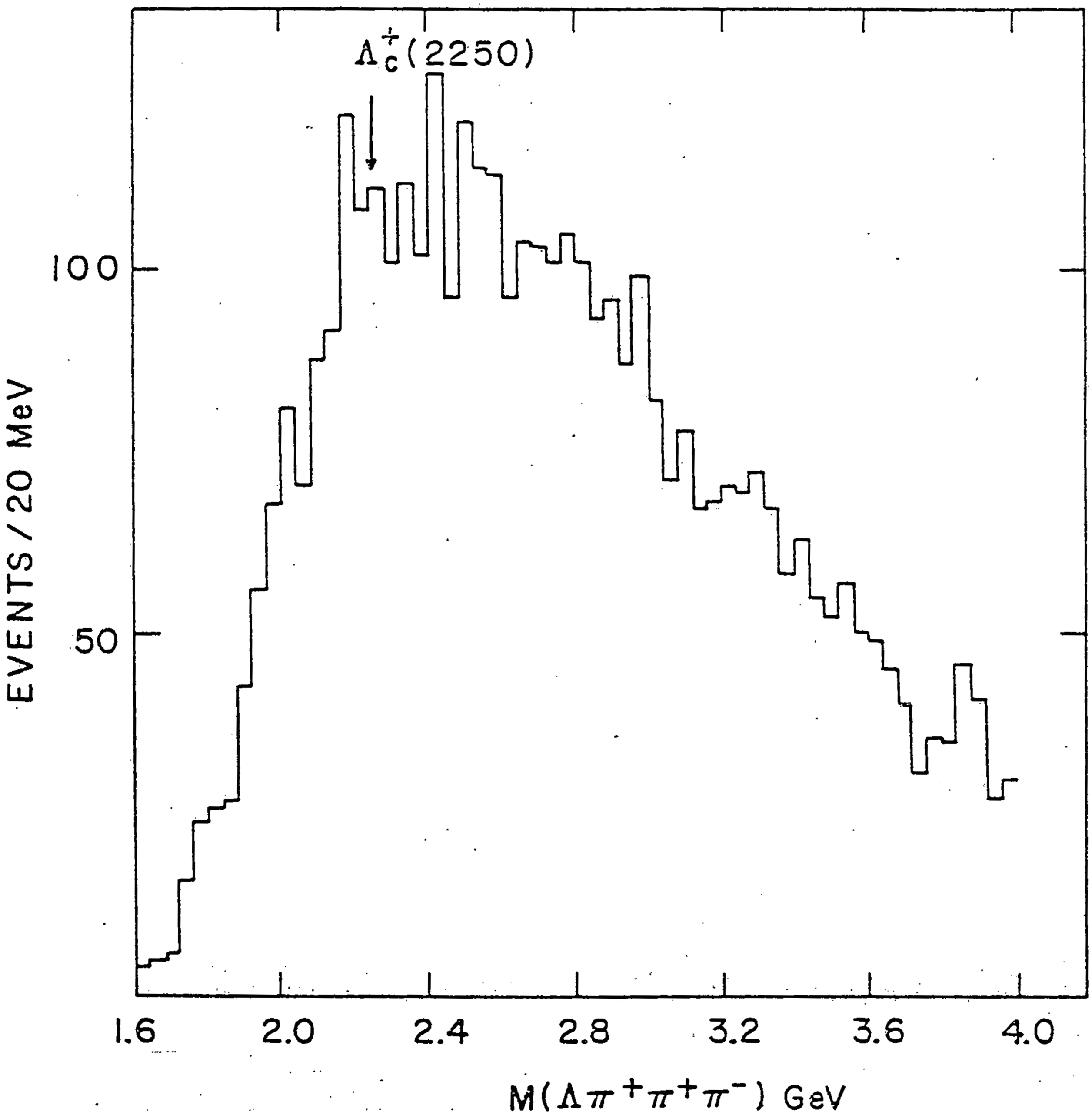

Figure 4. Effective mass distribution for $\Lambda\pi^+\pi^+\pi^-$ system.

5-716-78

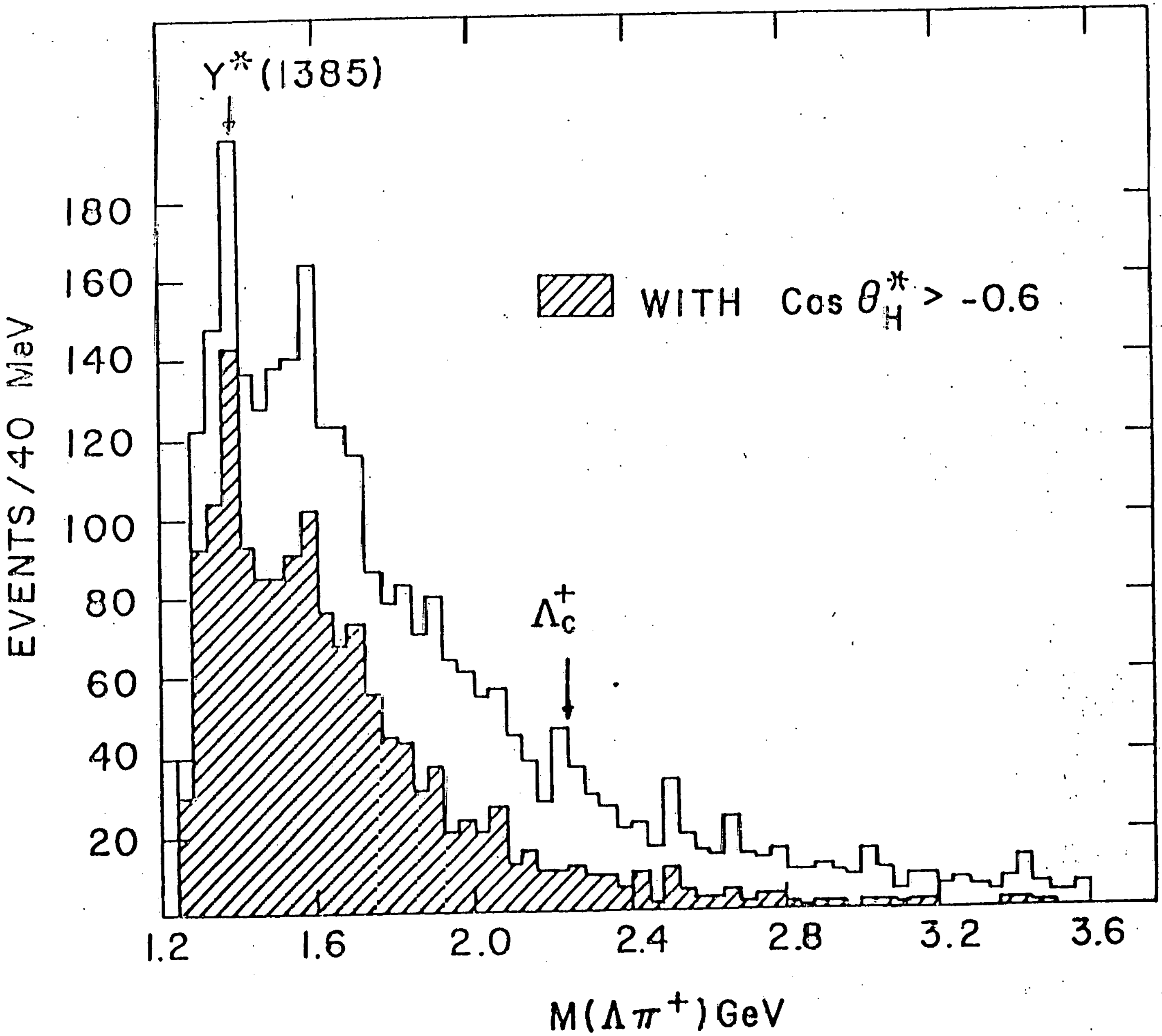

Figure 5. Effective mass distribution for $\Lambda\pi^+$ system. The shaded area indicates the distribution for events with $\cos\theta_H > -0.6$, where θ_H is the helicity angle of the Λ in the $\Lambda\pi$ system.

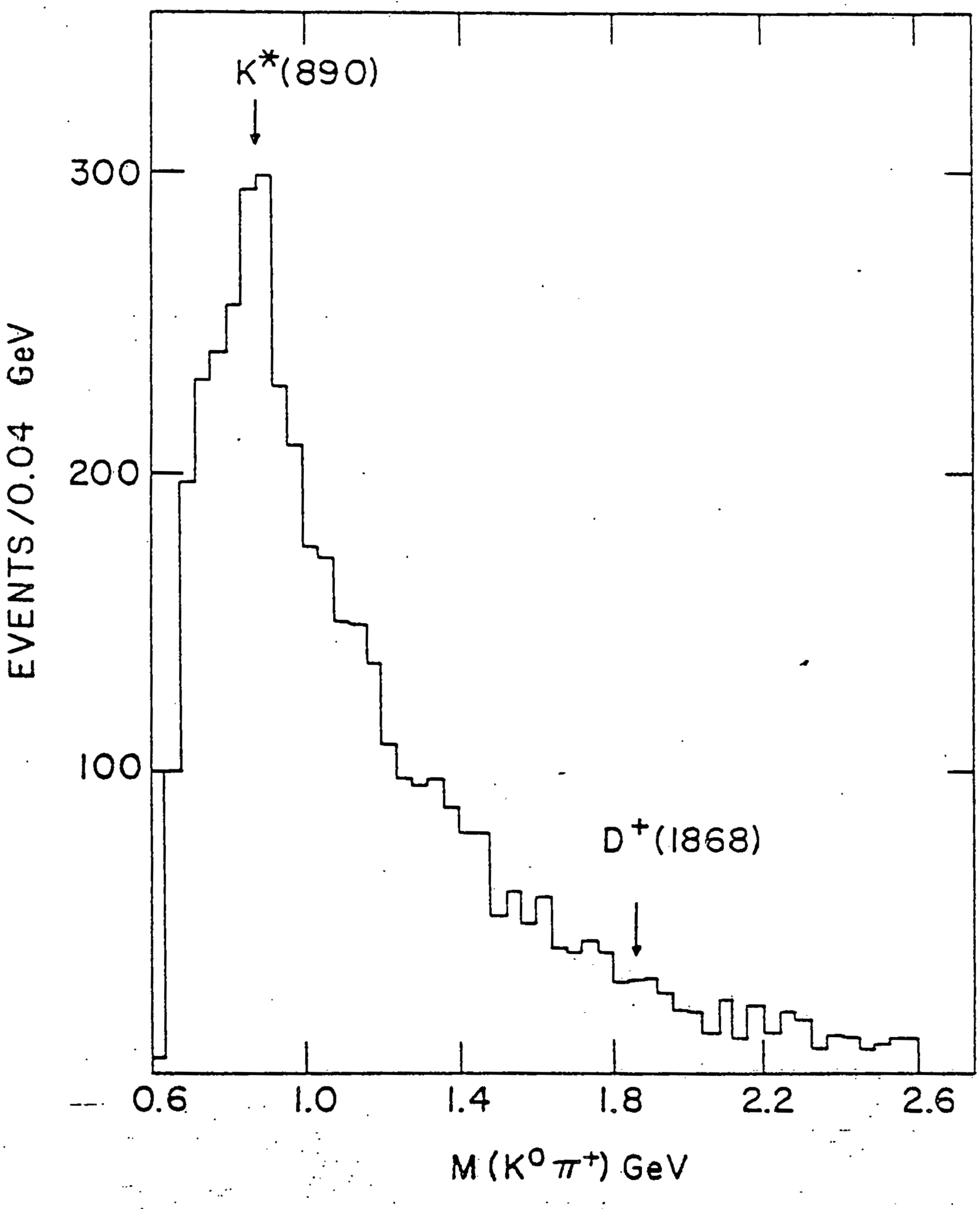

Figure 6. Effective mass distribution of $K^{0}\pi^{+}$ systems.

5-375-78

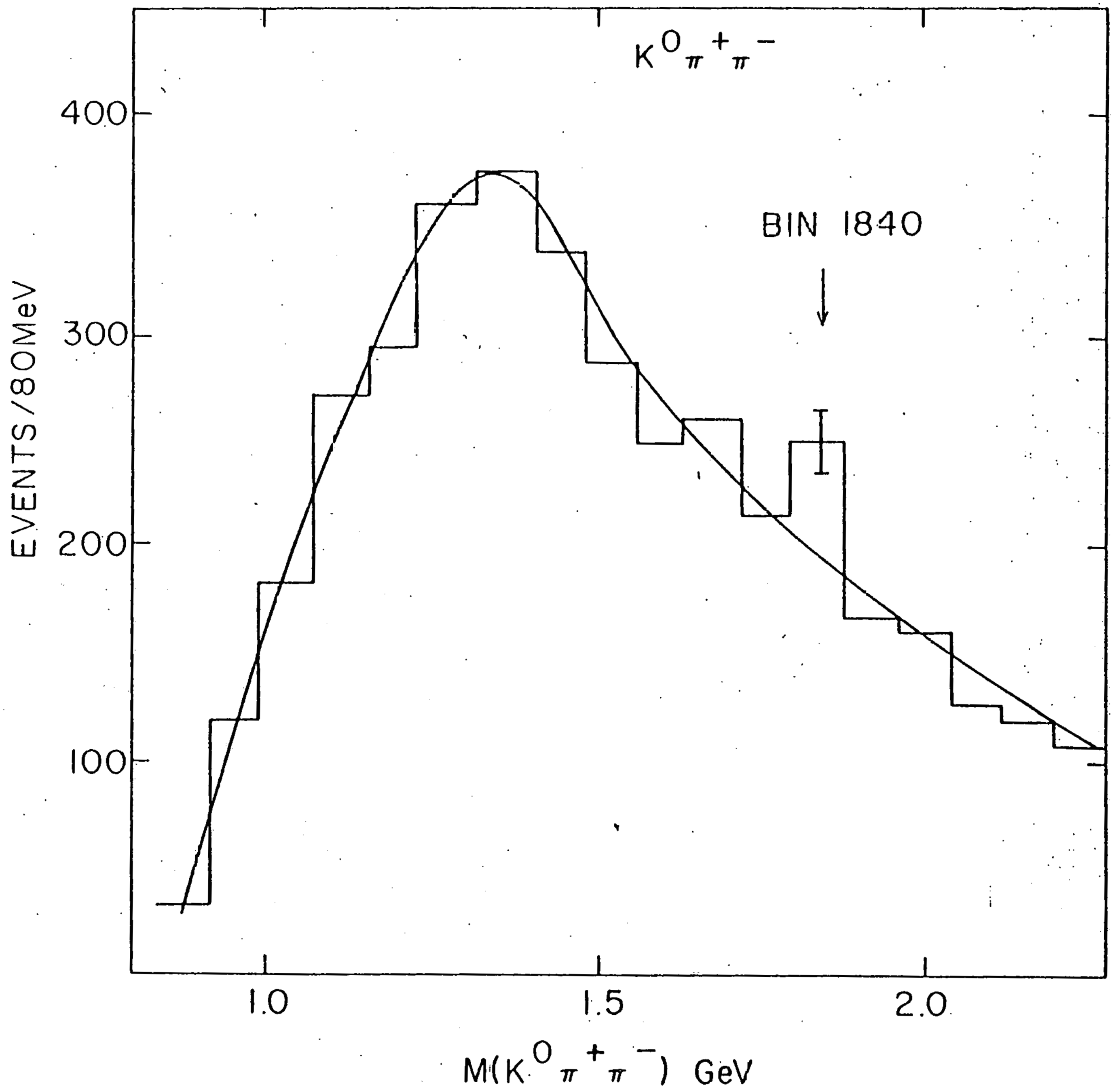

Figure 7a. Effective mass distribution of $K^o\pi^+\pi^-$ system plotted in 80 MeV bins.

5-376-78

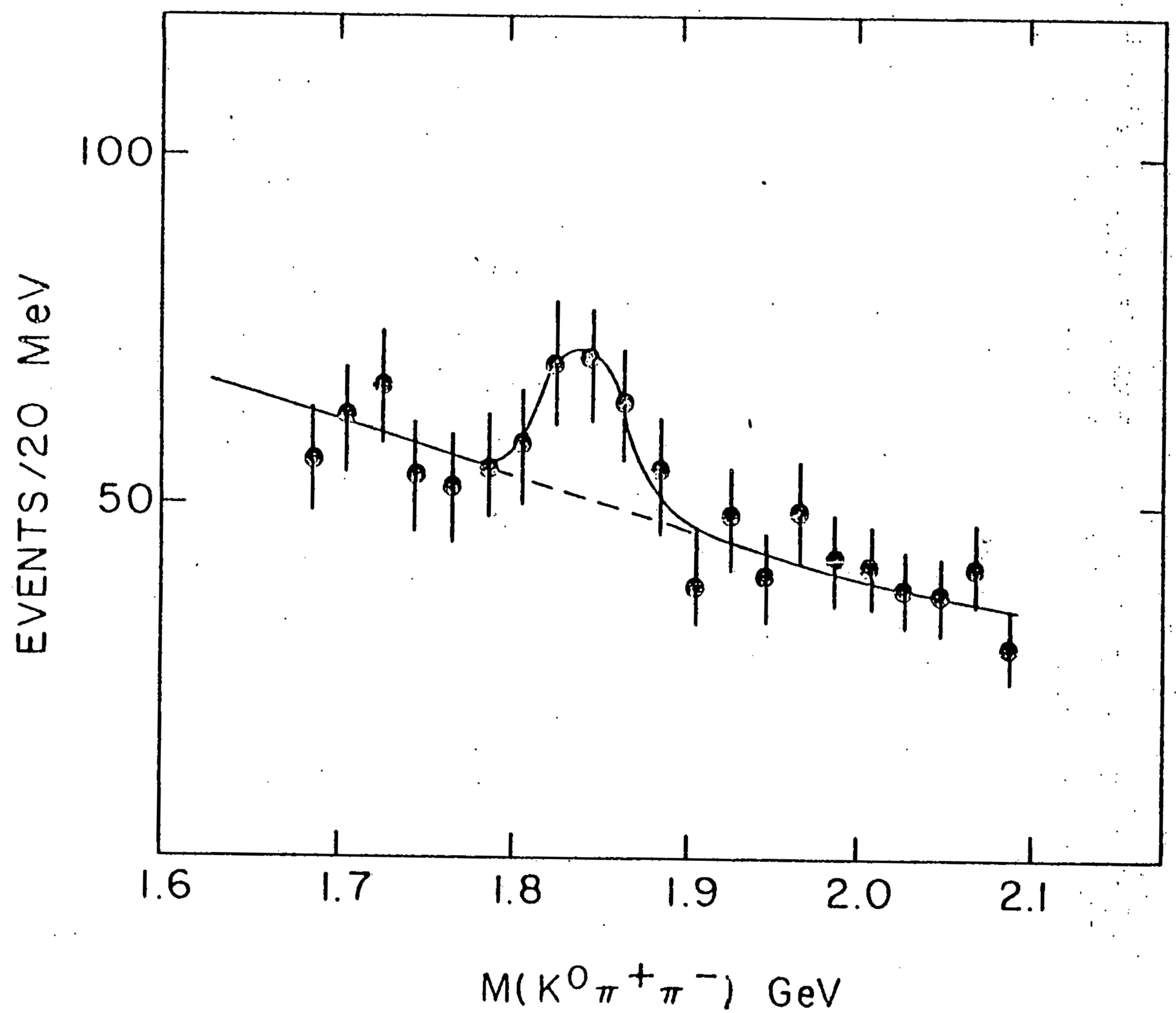

Figure 7b. Effective mass distribution of $K^0\pi^+\pi^-$ system plotted in 20 MeV bins. The polynomial plus gaussian fit is shown by the continuous line, the polynomial alone being indicated by the broken line.

8). This might be considered evidence for a meson containing a quark of the type present in the T(9.5). However, if the enhancement were of this origin then its branching ratio times fraction of charged current events is 2.5%. A branching ratio greater than 10% seems unlikely thus implying that the production of the state occurs in 25% of all charged current events: a very unlikely situation. We conclude that the effect is probably a statistical fluctuation.

4. LEPTONIC DECAY OF CHARM

Charm is expected to be produced only in charged current events and the $\Delta C = \Delta Q$ rule requires that with neutrinos only positive charm can be made and the leptonic decay will then give a positive lepton (e^+ or μ^+) and a neutrino. Thus production and leptonic decay of charm will appear as events with a μ^- and μ^+, or μ^- and e^+. The μ identification in the chamber is not sufficient to identify the former but the latter can be identified with high efficiency (85%) and low background ($\leq$ 14%). 164 events with μ^- and e^+ were found. When corrections are made for scanning efficiency and identification we obtain a ratio of $\mu^- e^+$ events to all charged current events of 0.5 ± .15%. The y $(\frac{\nu}{E_\nu})$ and x $(\frac{q^2}{2M\nu})$ distributions for these events are shown in Figures 9 and 10. The y distributions can be seen to be consistent with a normal V-A interaction and inconsistent with V + A. The x distribution may be compared with that expected (continuous line) for production from a valence quark:

$$\nu + d \rightarrow \mu^- + c \tag{8}$$

The agreement is reasonable, but one does note a slight enhancement at low x which when fitted (broken line) indicates a 25 ± 25% contribution from the strange quarks in the sea reaction:

$$\nu\ s \rightarrow \mu^-\ c \tag{9}$$

We now consider the strange particle content. 33 of the 164 events also contain a V^o i.e. 20 ± 4%. This may be compared to the fraction of other charged current events with a V^o which is 6%. The excess is explained if the events come from charm decay by the expected dominance of charm decay to strangeness. If reaction 8 dominates then the expected excess (after correction for decay modes, efficiencies, and assuming equal charged and neutral strange particles would to 15%. At higher energies reaction 9 should eventually become dominant, two strange particles would be made per event and the visible excess would be

5-716=78

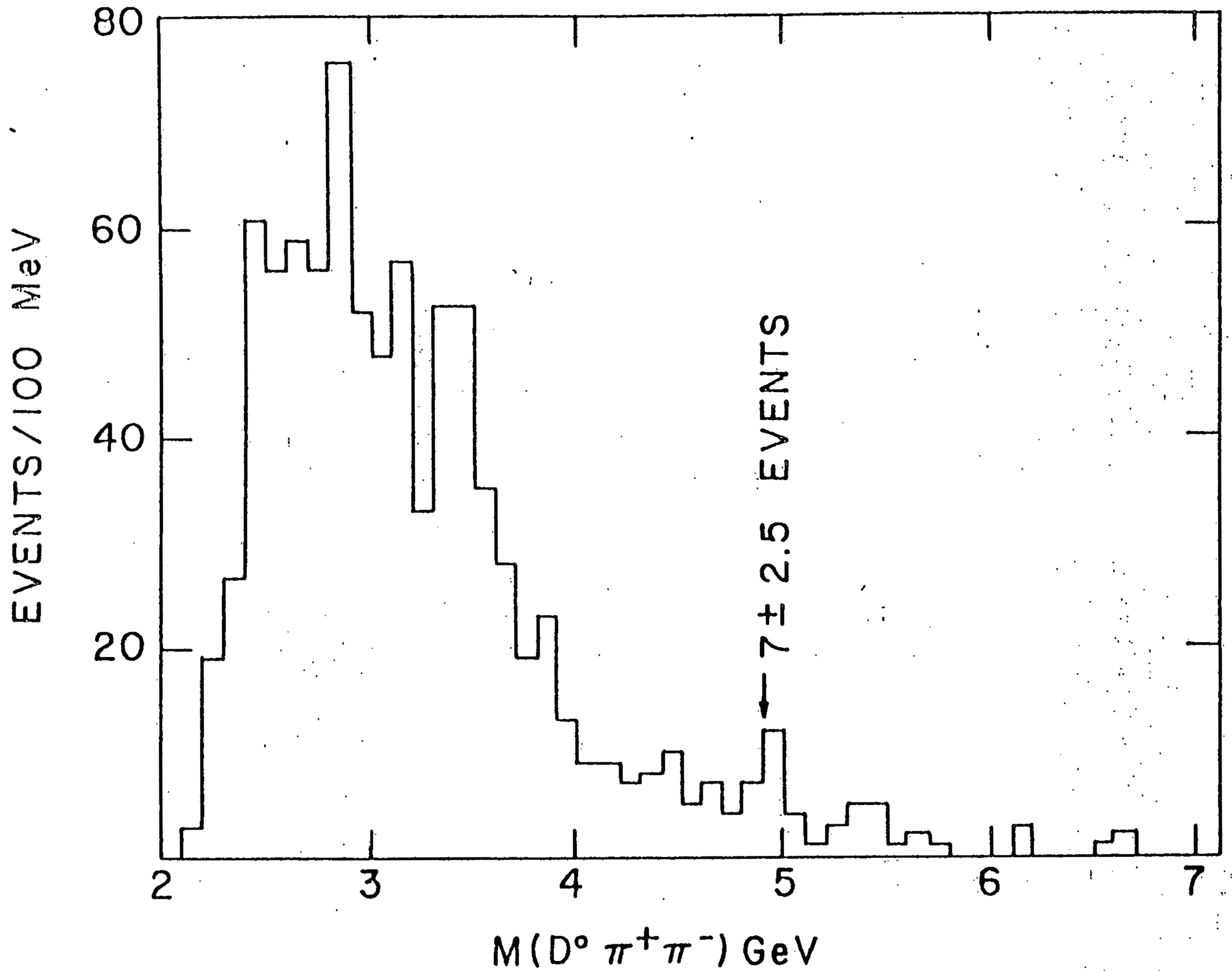

Figure 8. Effective mass distribution of the $D^{o}\pi^{+}\pi^{-}$ system.

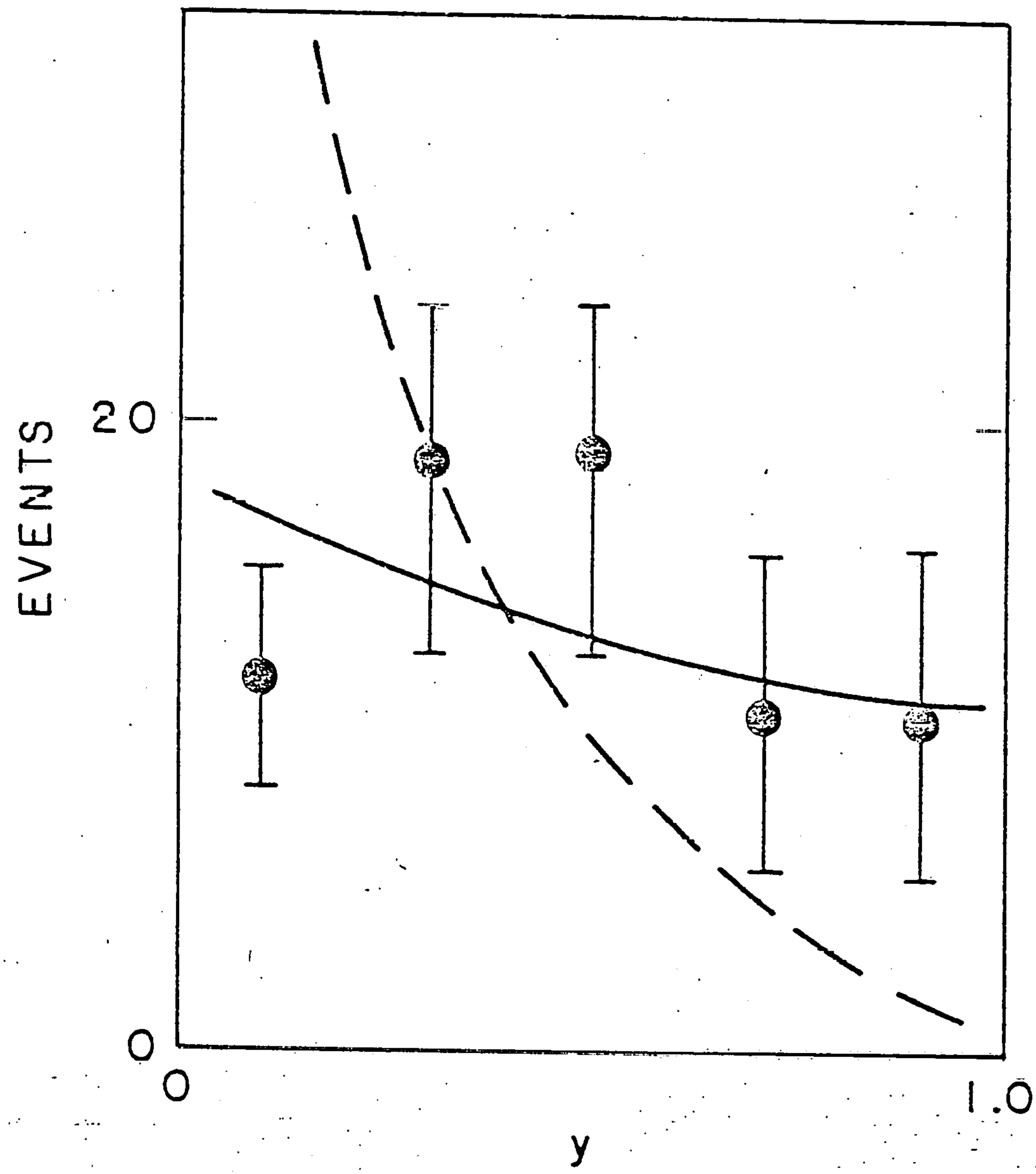

Figure 9. y distribution of events of the type ν_μ Ne $\to \mu^- e^+$ etc.

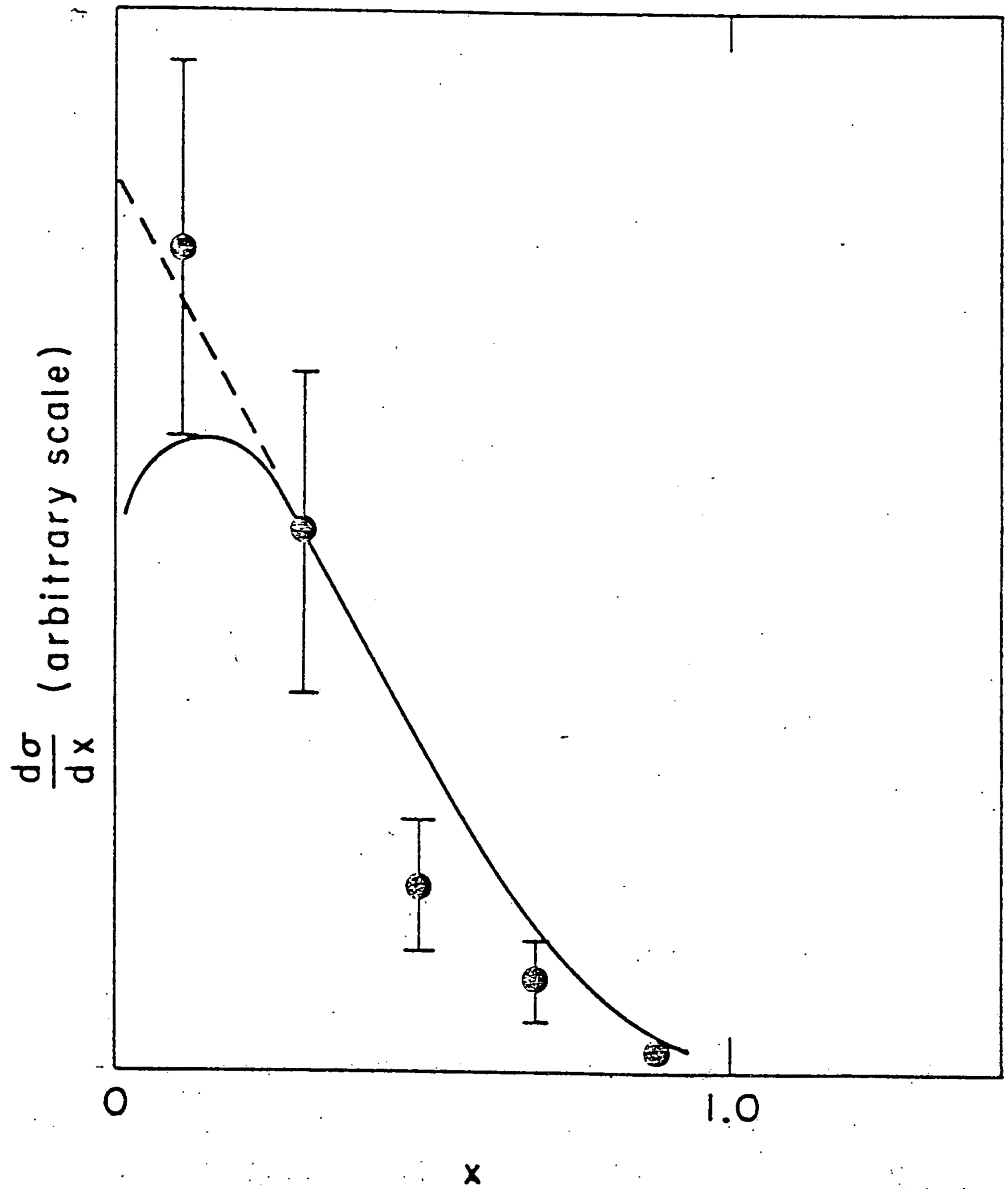

Figure 10. x distribution of events of the type ν_μ Ne $\rightarrow \mu^- e^+$ etc.

about 30%. In Figure 11 and Table I the fraction of V^o's observed by different experiments are plotted against an estimate of the mean neutrino energy in each case. The lowest dotted line indicates the expected contribution from associated strange particle production (unrelated to the charm); the second dotted line includes the contribution from reaction 1; and the dashed line is an arbitrary guess as to how the ratio might vary if production becomes dominated by reaction 2 above 60 GeV neutrino energy. This line is not the result of a calculation but shows that a higher ratio in the BEBC narrow band beam experiment (point 6) is consistent with what should be expected.

TABLE I

Fraction of V^o's Found in Dilepton Events from Different Experiments

#	Experiment	Beam	Average† E_ν	Total Dileptons	Total V^o's	Fraction* With V^o's
1	Gargamelle, Freon/propane	WB Ps	3	14 $\mu^- e^+$	3	.21 ± .11
2	CERN BEBC, Heavy Neon	WB SPS	20	21 $\mu^- e^+$	6	.29 ± .10
3	NAL 15', Light Neon	WB NAL	25	17 $\mu^- e^+$	11	.65 ± .12
4	NAL 15', Heavy Neon (E 172)	WB NAL	25	6 $\mu^- e^+$	1	.13 ± .12
5	NAL 15', Heavy Neon	QT NAL	40	9 $\mu^- \mu^+$	1	.11 ± .10
6	CERN BEBC, Heavy Neon	NB SPS	75	7 $\mu^- \mu^+$ 5 $\mu^- e^+$	4 2	.5 ± .14
	THIS EXPERIMENT	WB NAL	25	164 $\mu^- e^+$	33	.2 ± .03

Abbreviations: WB Wide band horn focus
QT Wide band quadruple triplet
NB Narrow band
NAL FNAL (Fermilab)

* Errors given are statistical only.

† These values are approximate only.

Of the 33 events with strange particles 23 ± 3 are K^o's and 10 ± 3 and Λ's or Σ^o's. The errors arise because of ambiguities. The expected numbers from associated production are 5 and 4, respectively from which we obtain a ratio of charm decay to K^o over that to Λ/Σ^o of 6 ± 4.7. The

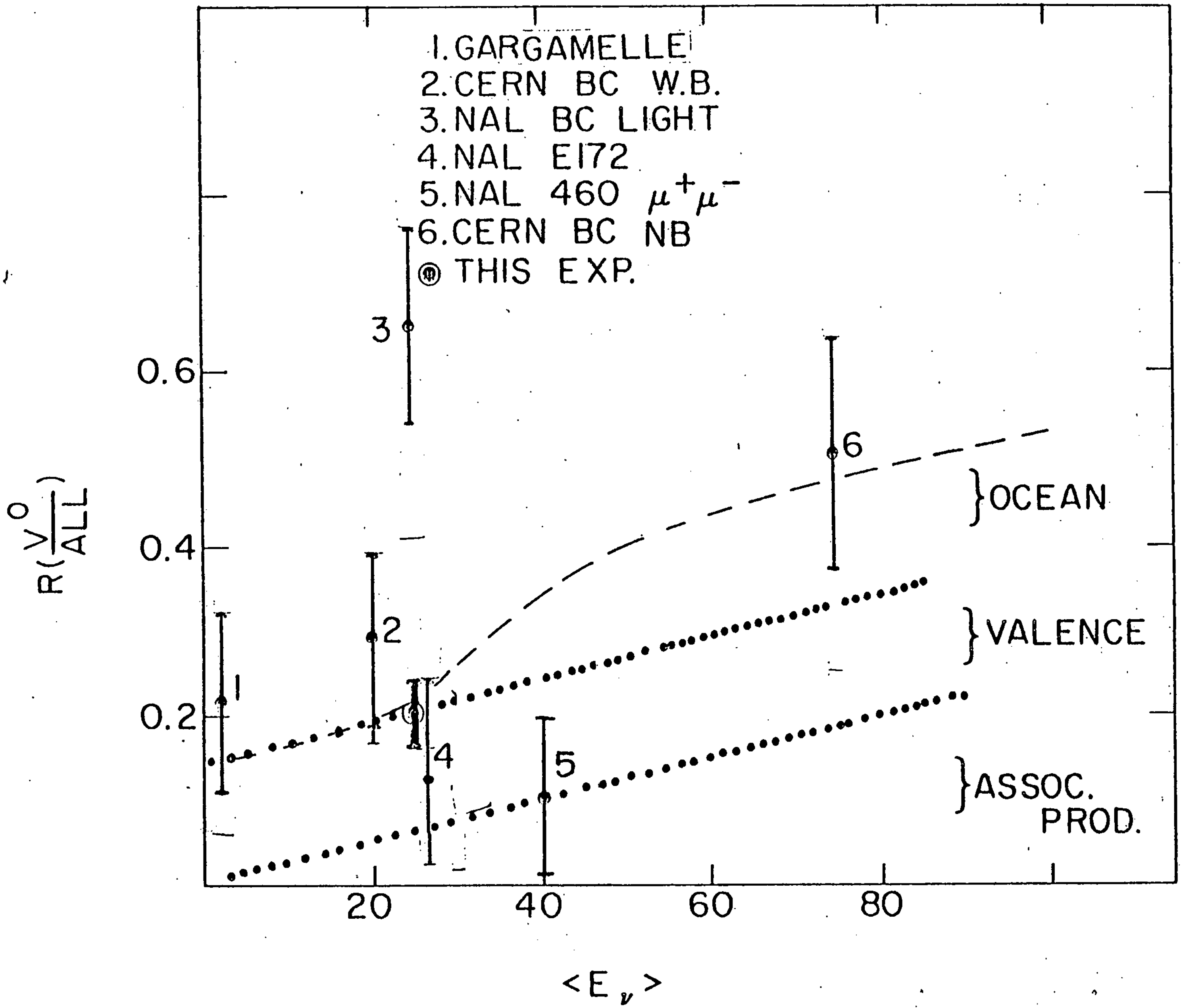

Figure 11. For events with two final charged leptons, the fractions (R) that have a visible V^o is plotted against the mean neutrino energies for seven experiments.

errors are large but suggest relatively small charmed baryon production relative to meson production, a result also suggested by the limits on hadronic decays (equations 6).

Assuming that the events with a K^o do come from D decay, we can plot the effective mass of the K^oe^+ system and compare the distribution with that expected for different decay modes. For this purpose only unambiguous K^o's are used (Figure 12b). If the decay were

$$D^+ \rightarrow e^+ \nu K^o \tag{10}$$

then the distribution should be as shown by the dashed line (the curve is 3 body phase space but calculations including guessed form factors give very similar curves). Alternatively if the decay were

$$D^+ \rightarrow e^+ \nu K^o \pi^o \tag{11}$$

or

$$D^o \rightarrow e^+ \nu K^o \pi^- \tag{12}$$

the distribution should be as given by the continuous line (four body phase space). The distribution strongly favors this latter hypothesis. One explanation would be that there are far more D^o's than D^+'s as suggested by the hadronic decays (equation 7). If this were the case then decay (12) is dominant and one should be able to find the π^- by requiring the $\pi^-K^oe^+$ mass to be less than the D mass. Of the 16 events with unambiguous K^o's, 12 have only one candidate π^- and 4 have two such candidates. The π^-K^o mass for these events is plotted in Figure 12a. the distribution observed is consistent with the phase space curve indicated. There is little evidence for the π^-K^o's being from the $K^*(890)$.

Finally we can compare the hadronic and leptonic decays branching ratios. We obtain

$$\frac{D^o \rightarrow K^o\pi^+\pi^-}{D^o \rightarrow \nu e^+ \text{ etc}} \geq 1.4 \pm .7 \tag{13}$$

where the limit is reached when there is no D^+ production. The above limit may be compared with the SLAC observed ratio

$$\frac{D^o \rightarrow K^o\pi^+\pi^- \; (4 \pm 1.3\%)}{D^{+/o} \rightarrow e\nu\ldots(7.2 \pm 2.8)} = 0.56 \pm 0.28 \tag{14}$$

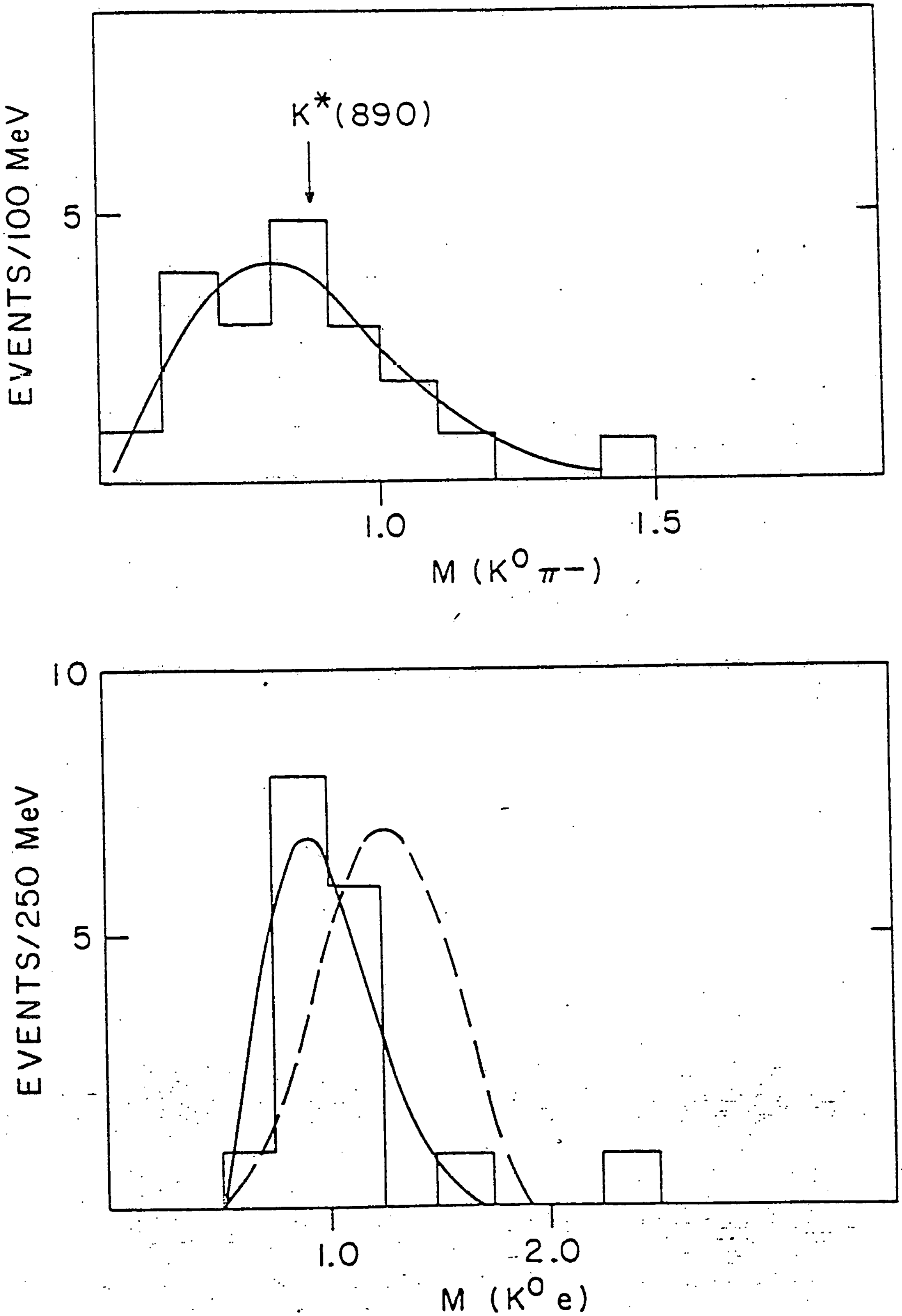

Figure 12. (a) Effective mass distribution of the $K^o\pi^-$ system for events of the type ν_μ Ne $\rightarrow \mu^- e^+ K^o\pi^-$ etc. for which the effective mass of $e^+ K^o\pi^-$ is less than 1.86 GeV. (b) Effective mass distribution of the K^oe^+ system for events of the type ν_μ Ne $\rightarrow \mu^- e^+ K^o$ etc. Events with 2 V^o's or ambiguous Vo's have been removed.

The apparent discrepancy between equations (13) and (14) could be explained if the semileptonic decay rate of the D^o were much less than that for the D^+. One notes however that the errors are large.

5. ELECTRON NEUTRINO EVENTS

Events were selected with an e^+ or e^- but no μ^- candidate. 28 such events were seen with an e^+ and 187 with an e^-. Such events can come from $\bar{\nu}_e$ and ν_e respectively but could also come from the decay of heavy muon type leptons. In order to set a limit on this latter hypothesis the expected numbers of $\bar{\nu}_e$ and ν_e events were calculated and thus any excess calculated. We obtained:

$$\begin{aligned} \text{excess } e^- &= 187 \pm 14 \text{ (observed)} \quad 215 \pm 60 \text{ (calculated)} = -28 \pm 60 \\ \text{excess } e^+ &= 28 \pm 6 \text{ (observed)} \quad -23 \pm 8 \text{ (calculated)} = 5 \pm 10 \end{aligned} \tag{15}$$

Clearly there is no significant excess. An independent test as to whether these events are indeed due to ν_e and $\bar{\nu}_e$ is provided by the distributions of the events in y_{viz}, where $y_{viz} = (E_{viz} - E_e)/E_{viz}$. These distributions are given in Figures 13 and 14 where the continuous lines indicate the expectation for $\bar{\nu}_e$ and ν_e interactions and the broken lines indicate that expected if the e's were coming from the decay of a τ meson (eg., $\tau^- \to e^- \bar{\nu}_e \nu_\tau$), where the τ^- is assumed to have the same distribution as a μ^- in a normal charged current event. The events appear to be due to $\bar{\nu}_e$ and ν_e with no evidence of heavy leptons.

Quantitatively, these results give the following limits:

$$\frac{\text{No. of } e^\pm \text{ from heavy leptons}}{\text{all charged current events}} \begin{cases} \leq .3\ 10^{-3} \text{ for } e^- \\ \leq 1\ 10^{-3} \text{ for } e^+ \end{cases} \tag{16}$$

$$\text{Mass of heavy lepton } L^\pm \text{ (if } g_{L\nu_\mu} = g_{\mu\nu_\mu}) \begin{cases} \geq 7.5 \text{ GeV for } L^- \\ \geq 9 \text{ GeV for } L^+ \end{cases} \tag{17}$$

$$g_{\tau\nu_\mu}/g_{\mu\nu_\mu} \text{ (or } \tan^2\theta_M) \begin{cases} \leq .025 \text{ for } \tau^- \\ \leq .01 \text{ for } \tau^+ \end{cases} \tag{18}$$

The last result may be considered as a limit on a possible mixing angle θ_M between the ν_τ and ν_μ, in which case the limits apply to $\tan^2\theta_M$.

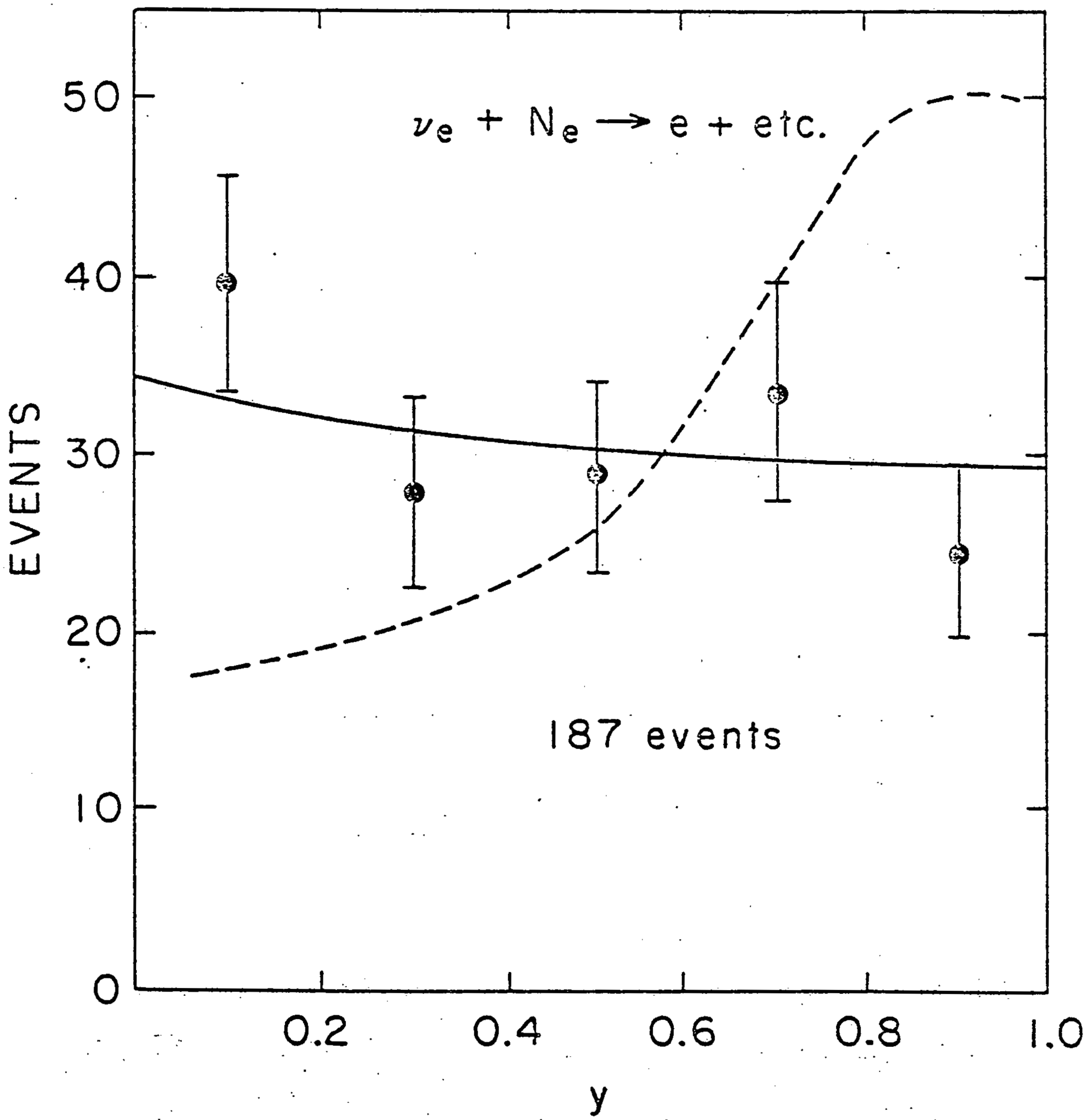

Figure 13. y distribution for events of the type ν_e Ne $\rightarrow e^-$ etc.

5-710-78

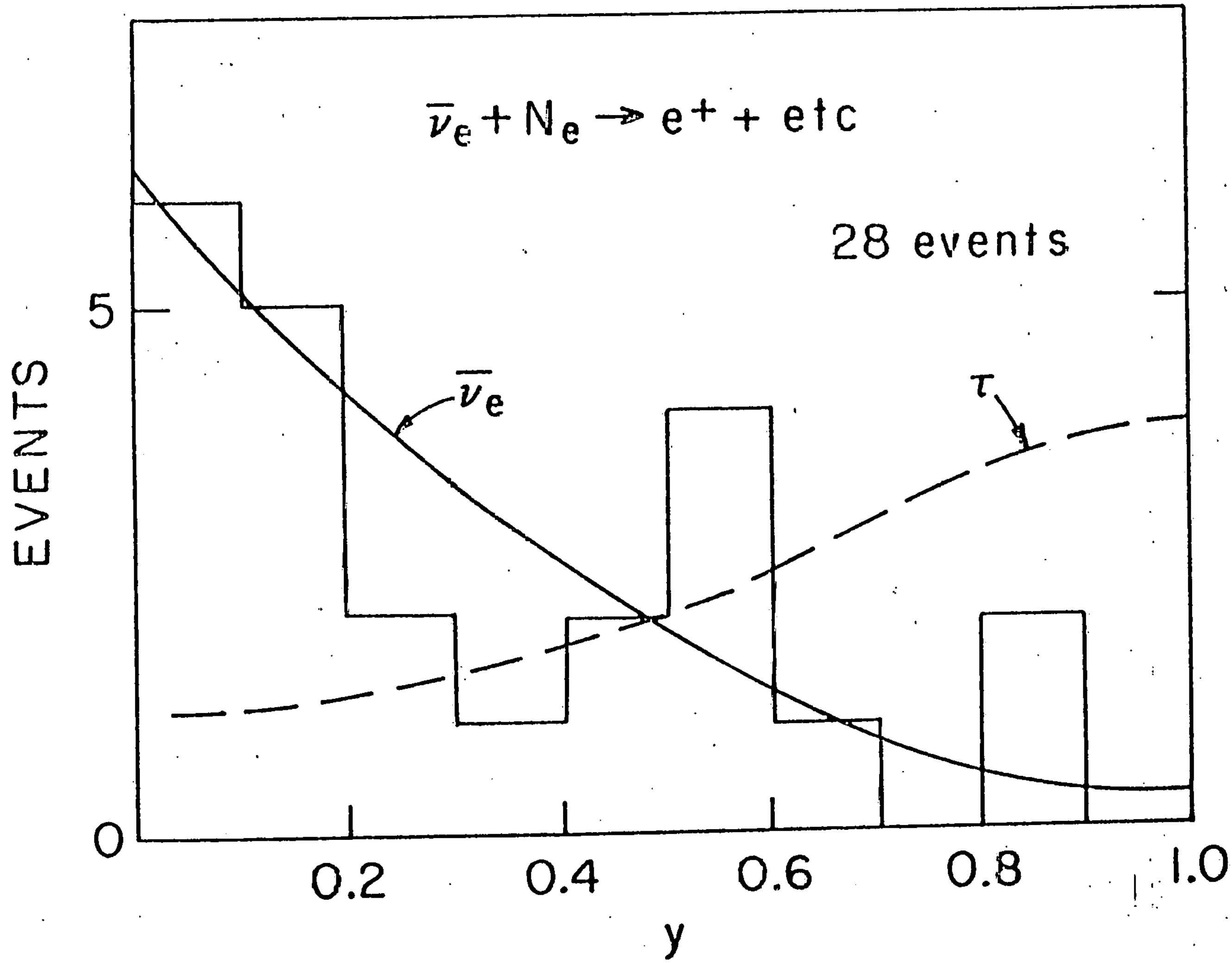

Figure 14. y distribution for events of the type $\bar{\nu}_e$ Ne $\rightarrow e^+$ etc.

6. OTHER EXOTIC STATES

Finally we can report two non observations: We have seen no trilepton events of the type $\mu^- e^+ e^-$. From this we obtain:

$$\frac{\text{Rate } \nu_\mu \rightarrow \mu^- e^+ e^- \text{ etc.}}{\text{Total charged current rate}} \leq 10^{-4} \qquad (19)$$

where $< E_\nu > \sim 20$ GeV and $M_{e^+e^-} \geq 500$ MeV. Such events would be made if there were neutral current charmed particle production. Thus we can obtain the limit:

$$\frac{\text{Neutral current charmed particle production}}{\text{Charged current charmed particle production}} \leq 2\% \qquad (20)$$

The second non observation concerns long lived neutral particles of the type reported by the Serpukov bubble chamber group.[1)] We have searched for neutral particles decaying in an e and μ with flight path greater than 5 mm. We have found no such event in 40,000 charged current events. Our scanning efficiency for such an event is greater than 50%.

This research was supported by the U.S. Department of Energy under Brookhaven National Laboratory Contract No. EY 76-C-02-0016.

REFERENCES

1. Physics Letters 70B, 269 (1977).