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OBSERVATION OF MUON-NEUTRINO REACTIONS PRODUCING A POSITRON AND A STRANGE PARTICLE

Aachen-Bruxelles-CERN-E.P. Palaiseau-Orsay-Milan-U.C. London

Gargamelle Collaboration

presented by M. Haguenauer

CERN, Geneva

ABSTRACT

Neutrino events, in which a positron is observed together with a strange particle and a negative muon, have been seen in the bubble chamber GARGAMELLE exposed to the CERN PS neutrino beam. A complete study of all the possible background sources has been made, and they have been found to be very low. The total observed number of muon-positron pairs indicates a strong correlation between the production of the strange particle and the lepton pair.

MH/mft

INTRODUCTION

In the usual charm sheme [1], charged current neutrino reactions can produce hadrons with charm quantum number + 1, with or without an additional particle of strangeness + 1. The produced charmed hadron may decay semi-leptonically into a positron, a neutrino and a particle of strangeness - 1. The most frequent charm changing reaction on a nucleon N is expected to be

$$\nu + N \rightarrow \mu^- + C ,$$

where C is a charmed baryon. A characteristic signal for the production of charmed hadrons is then the simultaneous occurence of a strange particle together with a positron at the neutrino interaction vertex, in addition to the negative muon signing the ν interaction.

1. EXPERIMENTAL CONDITIONS

The heavy liquid bubble chamber Gargamelle, with a fiducial volume of 3 m^3, filled with heavy freon (CF_3Br, radiation length 11 cm) has been exposed to the CERN PS neutrino beam. Two exposures, in 1971-72 and in 1975, have been done, giving a total of 5.7×10^5 pictures. The 1975 sample was obtained with the aid of the PS booster. Thus the total number of pictures examined represents a total of 1.4×10^{18} protons on target, corresponding to a sample of 44500 charged current interactions (97 % of the 1975 runs have been used for the background check corresponding to 34100 charged current interactions) above 1 GeV of energy.

2. EVENT SELECTION

The film has been scanned twice for all events with an electron or a positron at the neutrino interaction vertex or a close γ ray conversion or a V^0 possibly pointing to the vertex. The electrons are easily identified by bremsstrahlung or spiralization ; due to the short radiation length, there is no confusion between electron and non-electron tracks in this experiment. To be accepted as a good event, the electron has to satisfy several criteria. The curvature must be unambiguously defined in order to ensure a reasonable scan efficiency and to reduce the background coming from asymetric γ rays, candidates were only retained if the electron or positron energy was greater than 200 MeV.

Three events of the type $\mu^- e^+ V^o$ have been found, two of them have already been published [2,3]. The third one is shown in fig. 1. It consists of a negative track leaving the chamber without interacting, a positron, a positive unidentified track, a low energy proton and a V^o.

All these three events are candidates for the neutrino production of charmed particles. Table 1 shows the number of events of categories $\mu^- e^+$ without V^o, $\mu^- e^-$, $e^- V^o$ and e^+ found in the 1975 exposures.

3. BACKGROUND STUDY

3.1 Background

Two main sources of background could simulate the topology of the observed events. The first source of background is due to asymmetric Dalitz pairs or an asymmetric γ ray pair converting close to the neutrino vertex and thus simulating a positron attached to the vertex. The asymmetry percentages α_+ and α_- respectively for positrons and electrons have been estimated in the present experimental conditions by the study of γ rays converting far from the vertex in ordinary neutrino reactions. They were found to be $\alpha_+ = (1.1 \pm 0.7)$ % and $\alpha_- = (4.2 \pm 1.3)$ %. The probability p that a γ-ray appears attached to the neutrino vertex either because it is a Dalitz pair or because of a close materialization is found to be (4.2 ± 1.3) %. To obtain the background, the observed number of γ-rays in the events with strange particles is multiplied by the appropriate probabilities, resulting in $(8.4 \pm 6.1)\ 10^{-2}$ events. This estimation is conservative since it does not take into account the fact that the three $\mu^- e^+ V^o$ events have no associated γ-ray whereas the main contribution to the calculated background is multi-γ events.

The second contribution to the background could come from events of the type $\bar{\nu}_e + N \rightarrow e^+ + V^o + (\pi^-$ simulating a $\mu^-) +$ hadrons. The percentage of $\bar{\nu}_e$ events producing a strange particle and an unidentified negative particle has been calculated from the four similar events of the type $\bar{\nu}_\mu + N \rightarrow \mu^+ + V^o + (\pi^-$ simulating a $\mu^-) +$ hadrons observed in the $\bar{\nu}_\mu$ exposure, assuming μ-e universality. Since the $\bar{\nu}_e$ energy spectrum background in the ν_μ beam has a different shape from the $\bar{\nu}_\mu$ spectrum, the four events were weighted according to the flux ratio to correct for this energy dependence. This gives $(8.2 \pm 4.9)\ 10^{-3}$ events.

The other sources of background, such as semi-leptonic decay of various hadrons, have all been estimated to be negligible. The probability that the three observed events may be attributed to background is then 2×10^{-4}. It should be pointed out that since in the present experimental conditions the probability for a γ-ray to appear as an electron is much bigger as to appear as a positron, if the three $\mu^- e^+ V^o$ events were due to the background induced by asymmetric γ-rays, some eleven $\mu^- e^- V^o$ should have been observed whereas none was seen.

3.2 Background check

Using the same numbers and the calculated and measured [4] ν_e/ν_μ flux ratio for calculating the expected numbers of $\mu^- e^+$, $\mu^- e^-$, $e^- V^o$, e^+ events, we obtain the results shown in table 1 together with the observed numbers. Complete agreement is found except for the $\mu^- e^+$ channel where an excess of events is found. This indicates that the background has been well estimated, the $\mu^- e^+$ excess corresponding to $\mu^- e^+$ pairs without observed V^o.

The probability that the observed number of $\mu^- e^+$ events are due to the background is less than 10^{-3}.

3.3 Correlation between e^+ and V^o Production

If the rate of strange particle production was the same for $\mu^- e^+$ events as for ordinary neutrino events without e^+ at the vertex, a total of 265 $\mu^- e^+$ events without V^o would have been expected in the 1975 exposures. Sixteen such events were found in this same exposure. The probability of observing such a small number is only $\sim 10^{-4}$. This suggests a very strong correlation between e^+ and V^o production.

4. KINEMATICAL ANALYSIS OF $\mu^- e^+ V^o$ AND $\mu^- e^+$ EVENTS

4.1 $\mu^- e^+ V^o$

Table 2 shows the kinematical quantities of all $\mu^- e^+ V^o$ events. In all three cases a 3 c-fit was tried for both the Λ and K^o hypotheses. In the two first events both hypotheses fitted well, the third one fitted only the Λ.

We should mention also that one of the other $\mu^- e^+$ events shows a neutron star and 2 γ's pointing to a common origin different from any visible vertex. There is a candidate for a neutral Λ decay into neutron and π^o, supporting the Λ production in at least a fraction of these events. events.

The Λe^+ and $K^o e^+$ masses in table 2 have to be understood as lower limits for the $\Lambda e^+ \nu$ and $K^o e^+ \nu$ systems where the ν is not observed.

4.2 $\mu^- e^+$ EVENTS

Fig. 2-a shows the energy distribution of these events, together with the transverse momentum. The comparison with the same distribution for $\mu^- e^-$ events does not allow us to draw any conclusion.

The two dimension plot y_e as a function of y_μ ($y_e = (E_{vis}-E_e)/E_{vis}$, $y_\mu = (E_{vis}-E_\mu)/E_{vis}$) for $\mu^- e^+$ and $\mu^- e^-$ events is shown in fig. 3. In the $\mu^- e^-$ case, we can see a possible separation coming from the two ν_e and ν_μ background sources.

The ν energy independent variable $v = xy$ is also shown in fig. 4.

CONCLUSIONS

We conclude that our data strongly indicate the existence of a new type of interaction leading to a charged lepton pair and a strange particle in the final state. This is consistent with expectations based on the charm sheme [5].

REFERENCES

[1] D. Amati, H. Bacry, J. Nuyts and J. Prentki, Nuovo Cimento X34 (1964) 1732.

B.J. Bjorken and S.L. Glashow, Phys. Letters 11 (1964) 255.

S.L. Glashow, L. Iliopoulos and L. Maîani, Phys. Rev. D2 (1970) 1285.

A. de Rujula et al., Rev. Mod. Phys. 46 (1974) 391.

G. Altarelli, N. Cabibbo, L. Maîani and R. Petronzio, Phys. Letters 48B (1974) 435.

M.K. Gaillard, B.W. Lee and J.L. Rosner, Rev. of Modern Physics 47 (1975) 277.

M.K. Gaillard, S.A. Jackson and D.V. Nanopoulos, CERN/TH 0249 (1975).

[2] Strange Particle Production and Charmed Particle Search in Gargamelle Neutrino Experiment (Aachen-Bruxelles-CERN-E.P. Palaiseau-Milan-Orsay-and U.C. London Collaboration) presented by U. Nguyen-Khac.

La Physique du Neutrino à Haute Energie, Paris, March 1975.
H. Deden et al., Phys. Letters 58B (1975) 361.

[3] J. Blietschau et al., Phys. Letters 60B (1976) 207.

[4] T. Eichten et al., Phys. Letters 46B (1973) 281.

[5] J. Finjord and F. Ravndal, Phys. Letters 56B (1975) 61.

R.E. Shrock and B.W. Lee, Fermi Lab. Pub. 75/80 THY (1975).

TABLE 1

Topology	Found events	Expected number of events
$\mu^- e^+ V^0$	3	9×10^{-2}
$\mu^- e^+$ without V^0	16	5.0 ± 3
$\mu^- e^-$	23	25.6 ± 8
$e^- V^0$	5	$2.5 \pm .8$
e^+	6	5.4 ± 1.6

TABLE 2

	VERTEX				MUON						ELECTRON					
Event number	E_{vis}	P_L	P_T	μe mass	P	P_L	P_T	q^2	ν	W^2	P	P_L	P_T	q^2	ν	W^2
1	3.58	3.67	.85	.38	.18	.08	.13	.61	3.4	6.64	.25	.04	.25	1.49	3.33	5.64
2	3.87	3.91	.13	.43	1.07	.82	.67	1.86	2.81	4.29	.89	.64	.62	1.97	2.98	4.50
3	6.07	6.98	.56	1.31	.90	.59	.67	3.68	5.17	6.90	.77	.35	.69	5.16	5.30	5.67

Event number	Λ							K^o							
	P	P_L	P_T	life times	Fit Proba	Mass Λe	Mass Λeμ	P	P_L	P_T	life times	fit proba	Mass K^oe	Mass $K^o\mu e$	
1	2.09	1.40	1.54	.23	.43	1.24	1.65	1.80	1.21	1.33	.34	.70	.65	1.19	Units in
2	1.09	.79	.75	1.28	.45	1.91	2.64	1.41	1.02	.96	1.28	.29	1.57	2.38	GeV, GeV/c or GeV/c^2
3	3.67	3.64	.52	.23	.65	1.99	2.95	-	-	-	-	No fit	-	-	

FIGURE CAPTIONS

Fig. 1 $\mu^- e^+ V^o$ event.

Fig. 2 Visible energy and transverse momentum distribution of

a) $\mu^- e^+$ events

b) $\mu^- e^-$ events.

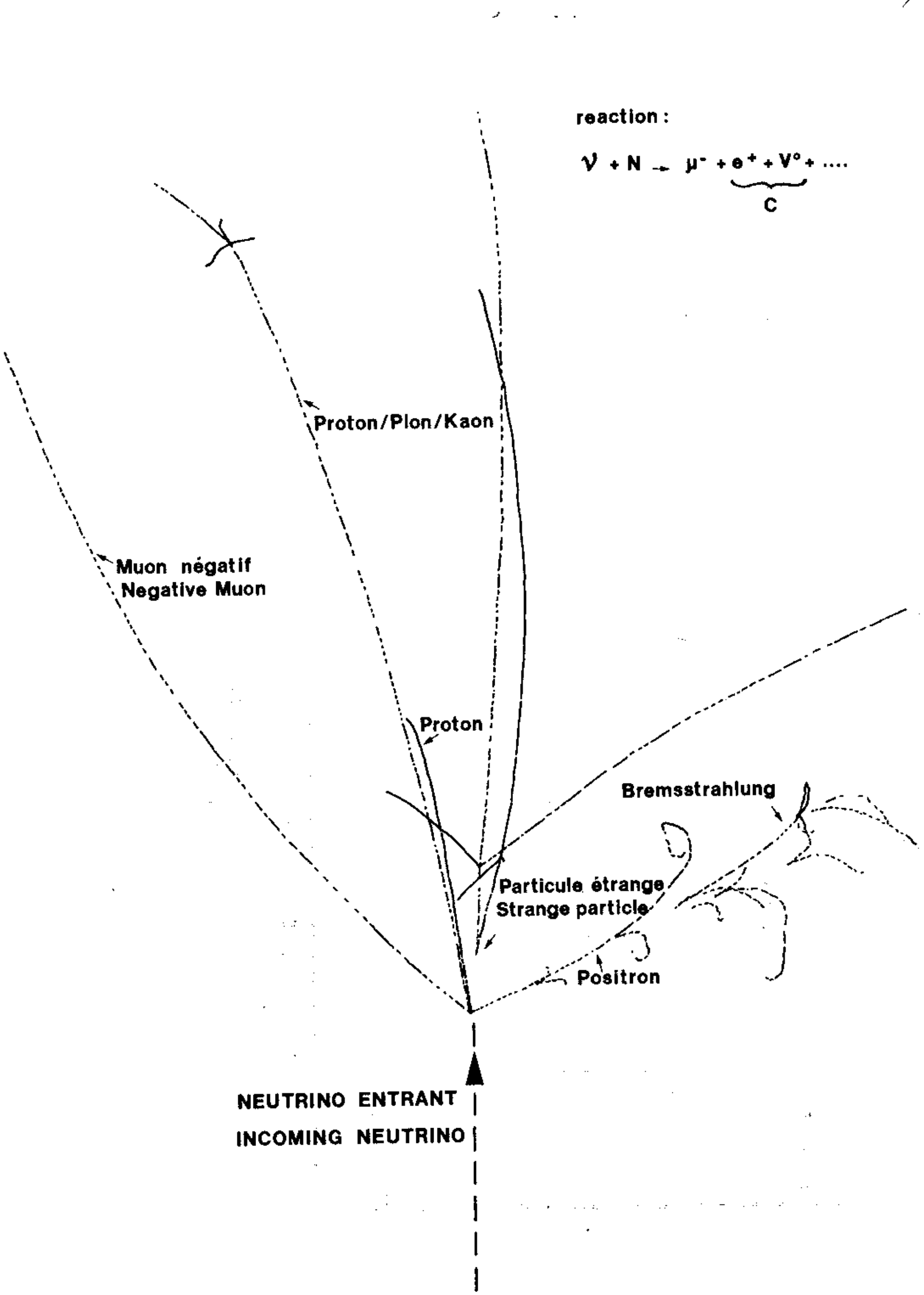
Fig. 3 Plot of $y_\mu = \frac{E_{vis} - E_\mu}{E_{vis}}$ versus $y_e = \frac{E_{vis} - E_e}{E_{vis}}$ for

a) $\mu^- e^+$ events

b) $\mu^- e^-$ events.

Fig. 4 Plot of v_e versus v_μ, with $v = x_{vis}\ y_{vis}$ ($x_{vis}\ y_{vis}$ are the scaling variables) for $\mu^- e^+$ events.

Fig. 5 Electron transverse momentum to the ν-μ plane distributions.



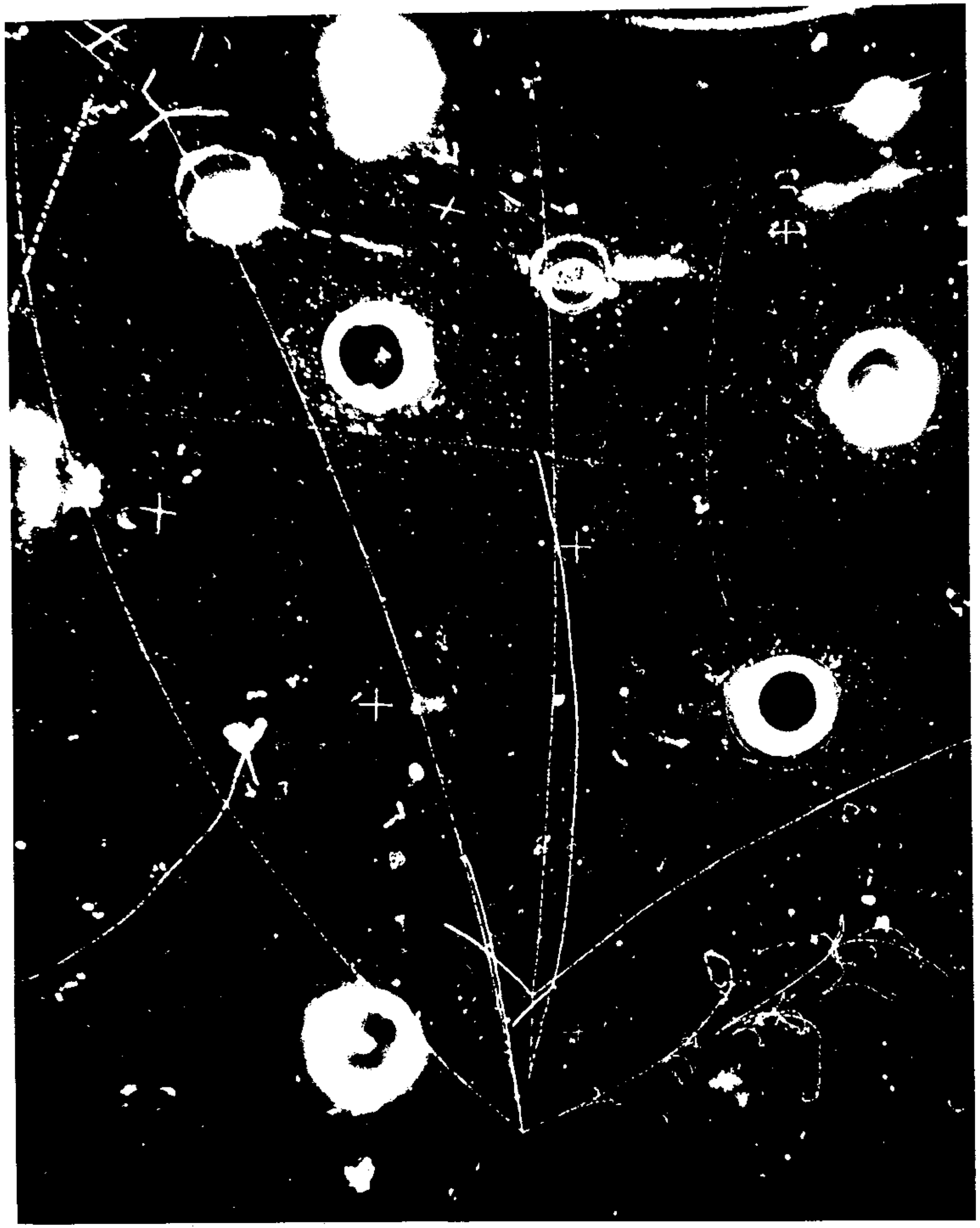


Fig. 1

reaction :

$\nu + N \rightarrow \mu^- + \underbrace{e^+ + V^\circ}_{C} + \ldots$

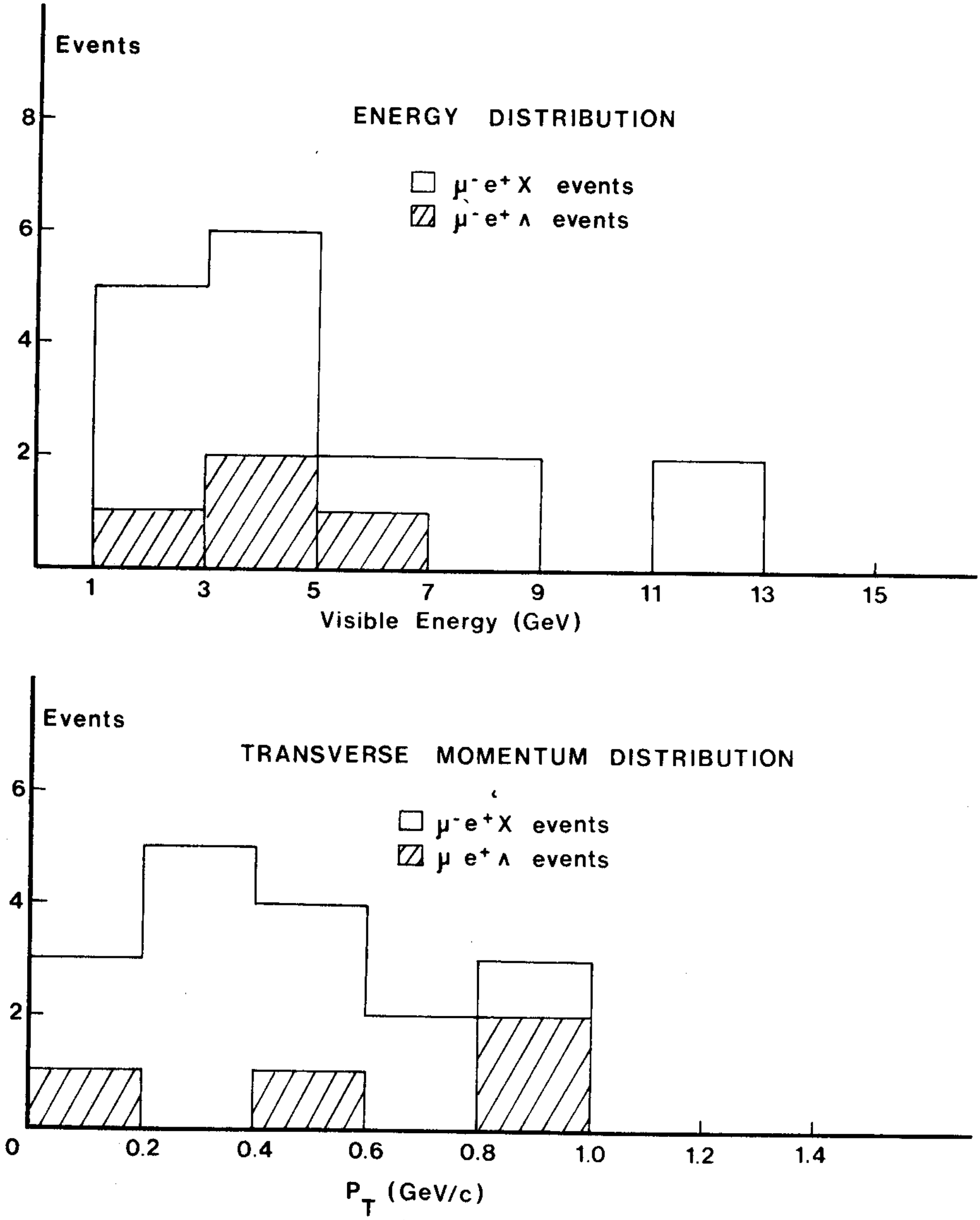

Events
ENERGY DISTRIBUTION
μ⁻ e⁺ X events
μ⁻ e⁺ Λ events
8
6
4
2
1
3
5
7
9
11
13
15
Visible Energy (GeV)
Events
TRANSVERSE MOMENTUM DISTRIBUTION
μ⁻ e⁺ X events
μ e⁺ Λ events
6
4
2
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
P_T (GeV/c)

Fig. 2a

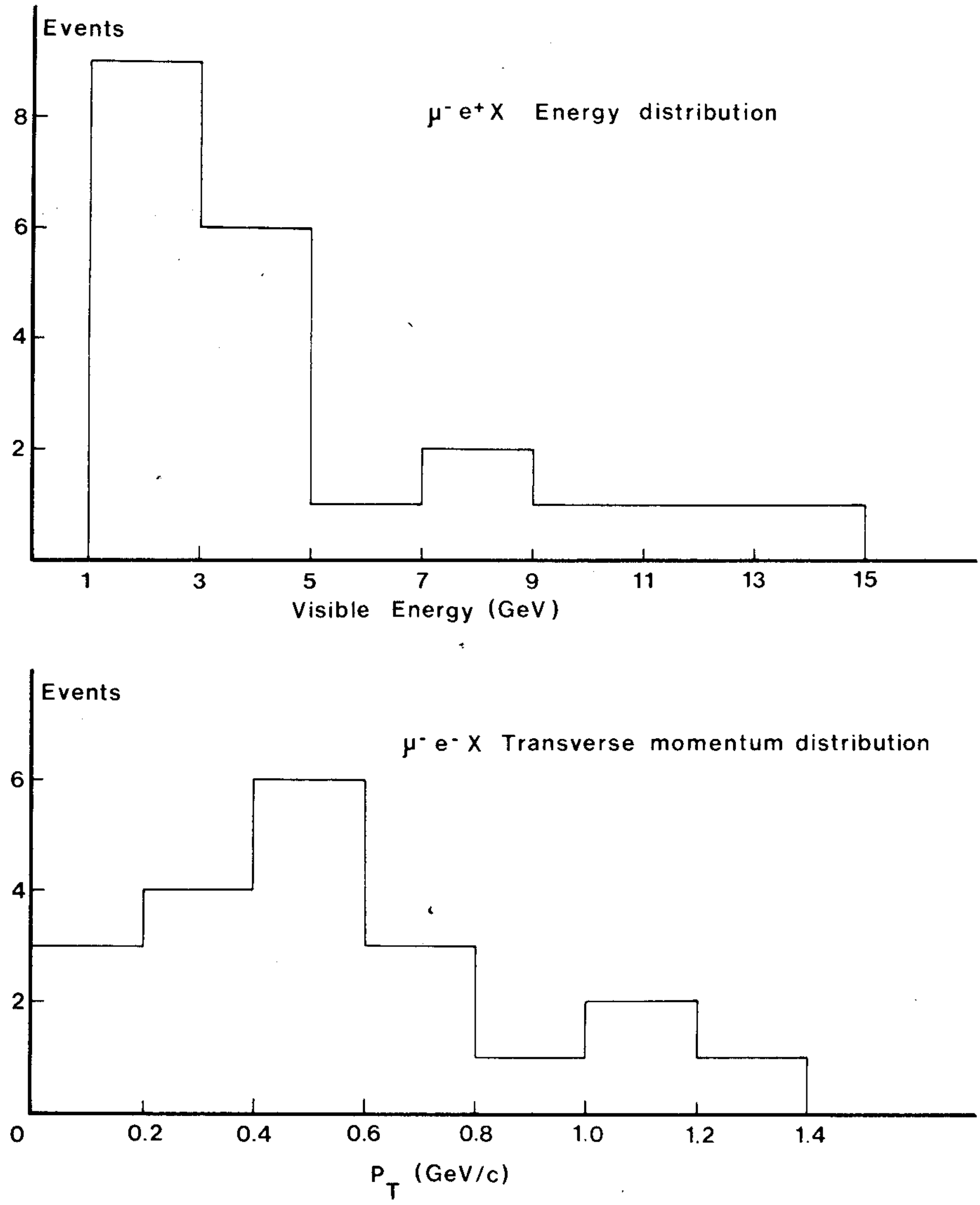
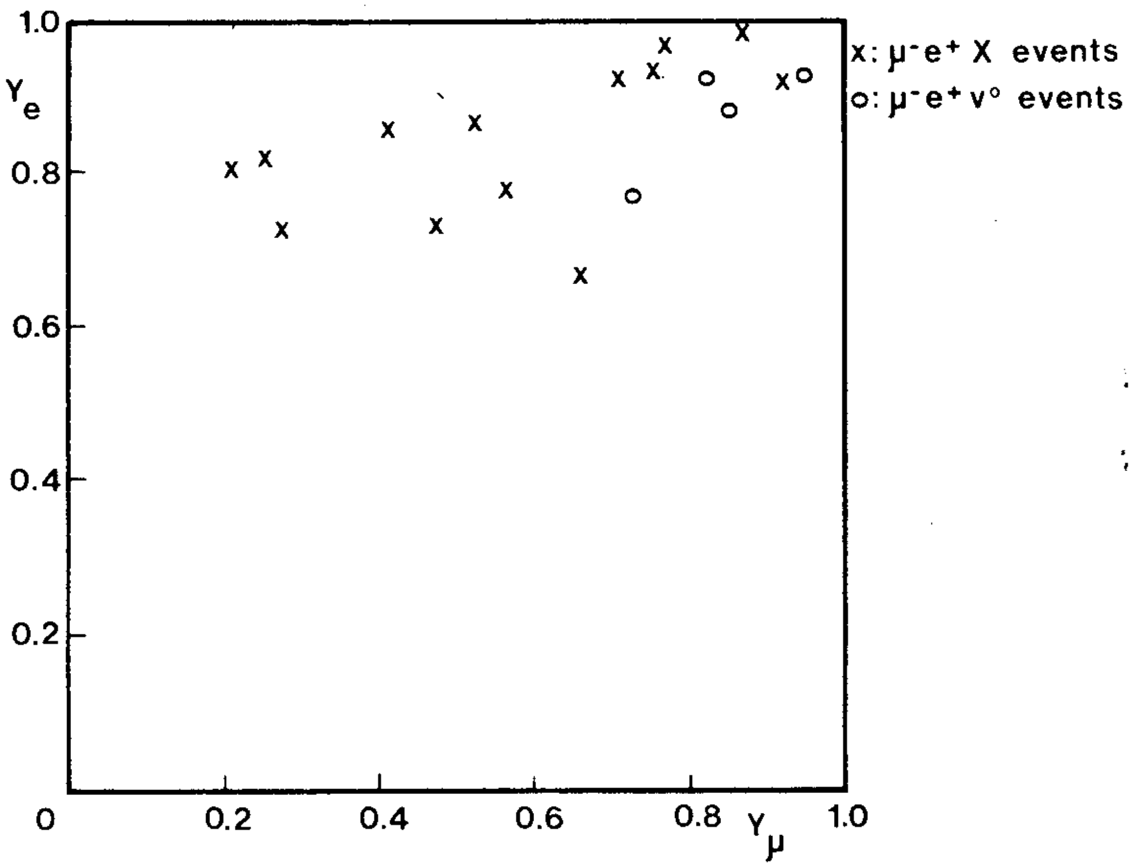

Events
μ⁻ e⁺ X Energy distribution
8
6
4
2
1
3
5
7
9
11
13
15
Visible Energy (GeV)
Events
μ⁻ e⁻ X Transverse momentum distribution
6
4
2
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
P_T (GeV/c)

Fig. 2b


1.0
Y_e
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
Y_μ
1.0
x: $\mu^- e^+ X$ events
o: $\mu^- e^+ v^\circ$ events

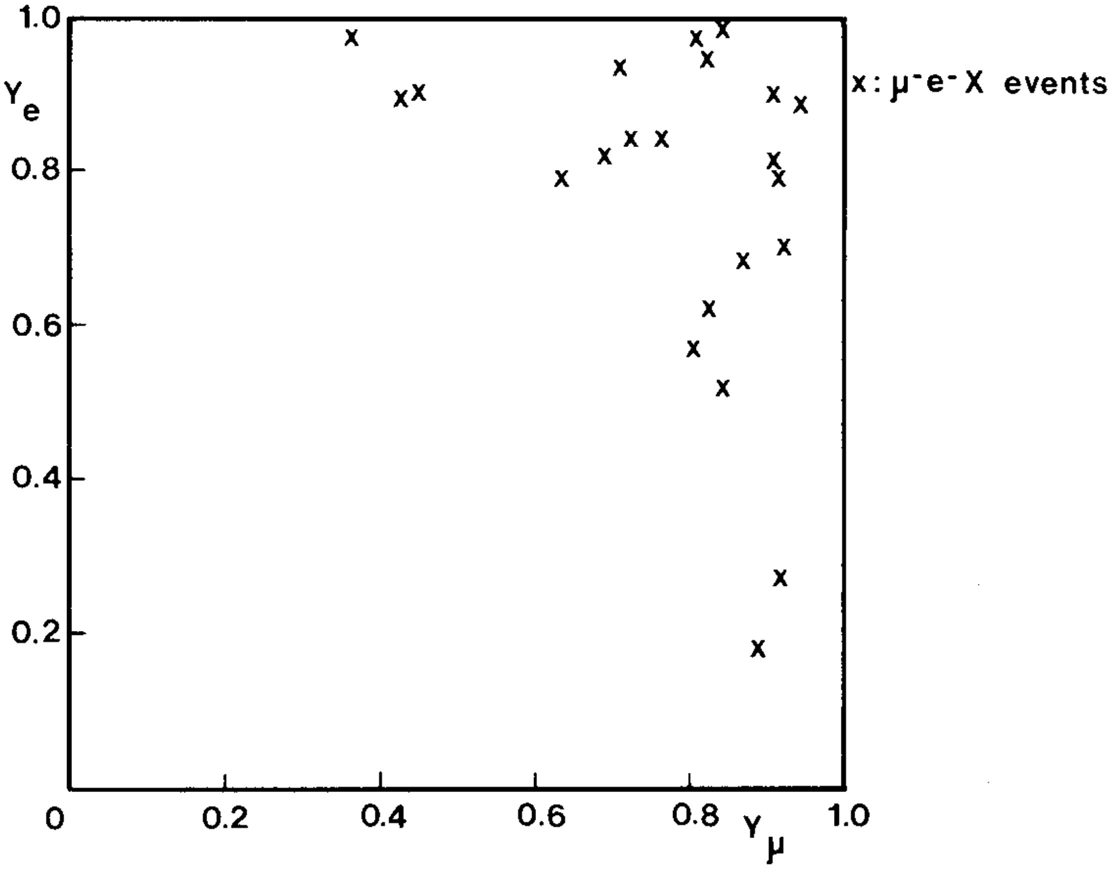
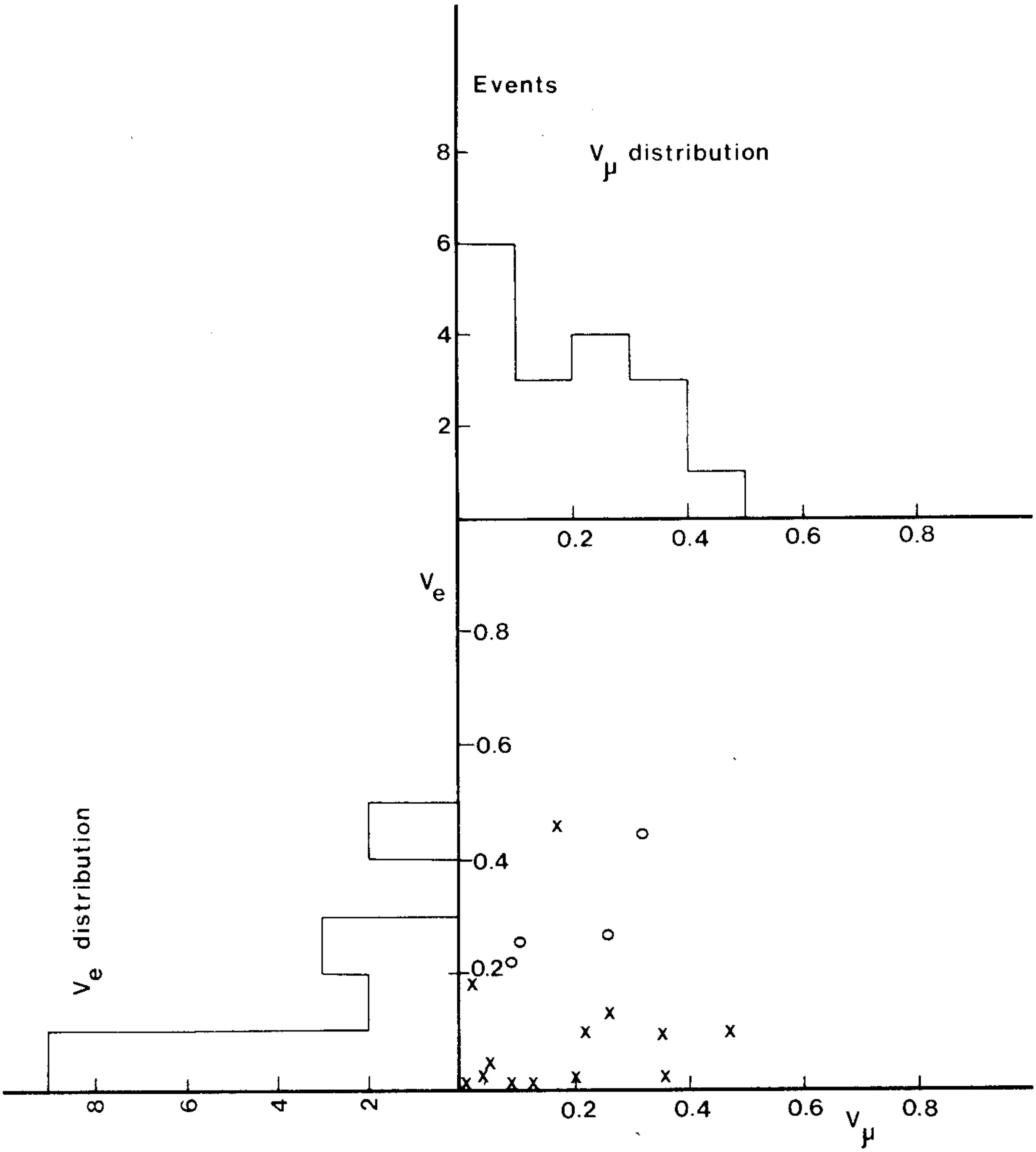

1.0
Y_e
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
Y_μ
1.0
x: $\mu^- e^- X$ events

Fig. 3



(V_e, V_μ) Plot for $\begin{cases} \circ : \mu^- e^+ \Lambda \text{ events} \\ x : \mu^- e^+ X \text{ events} \end{cases}$

Fig. 4

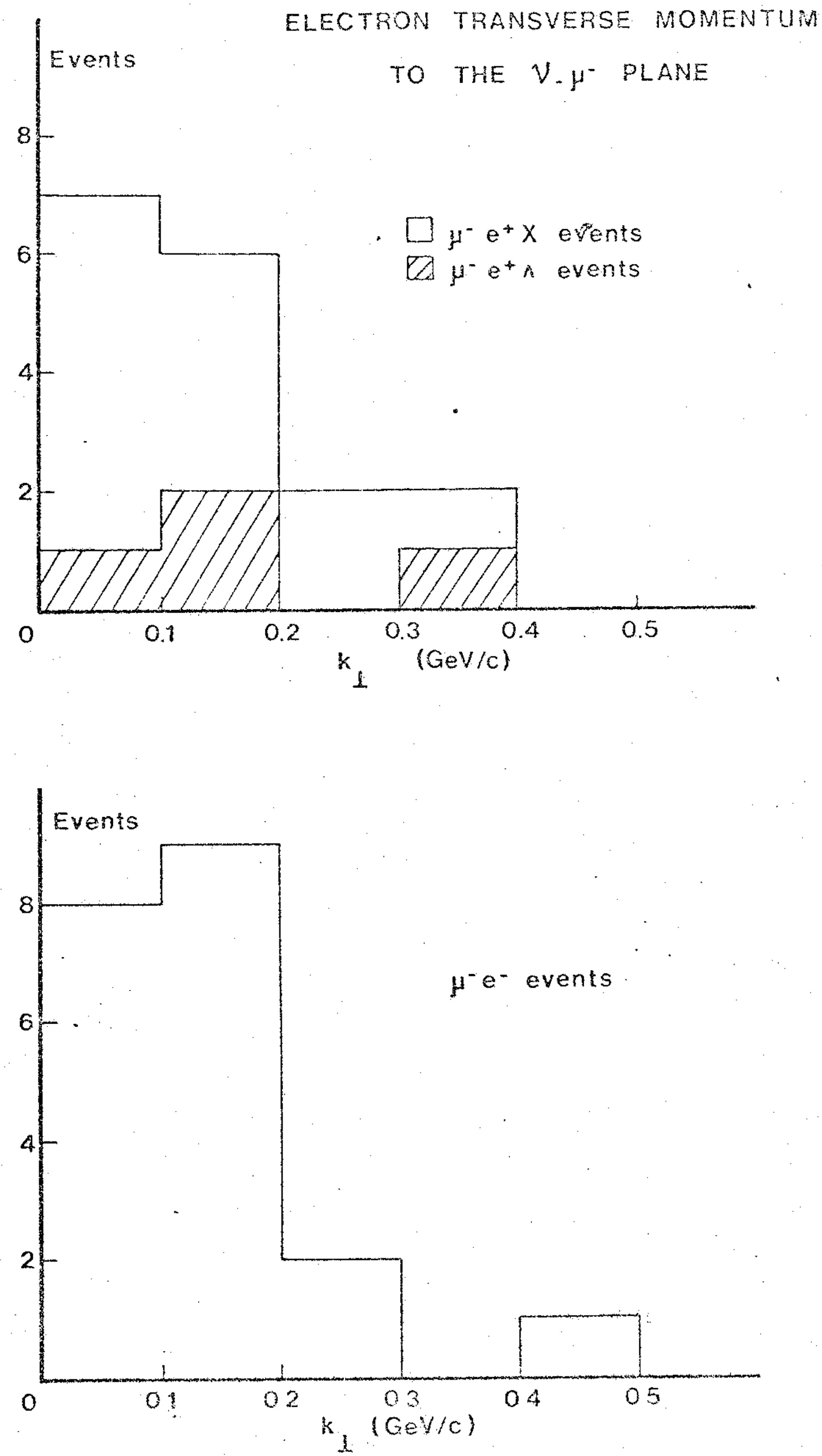

ELECTRON TRANSVERSE MOMENTUM
TO THE ν, μ⁻ PLANE
Events
8
6
4
2
0
μ⁻ e⁺ X events
μ⁻ e⁺ Λ events
0.1
0.2
0.3
0.4
0.5
k⊥ (GeV/c)
Events
8
6
4
2
0
μ⁻e⁻ events
0.1
0.2
0.3
0.4
0.5
k⊥ (GeV/c)

Fig. 5