CERN - EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Submitted to
Physics Letters B.

CERN/EP/PHYS 77-2
17 January 1977

DILEPTON AND STRANGE PARTICLES PRODUCTION BY NEUTRINOS IN GARGAMELLE

H. DEDEN, F.J. HASERT, W. KRENZ, D. LANSKE, J. MORFIN, M. POHL, K. SCHULTZE and L. WELCH
III. Physikalisches Institut der Technischen Hochschule, Aachen, Germany.

G. BERTRAND-COREMANS, H. MULKENS*, J. SACTON and W. VAN DONINCK**
Inter-University Institute for High Energies, U.L.B., V.U.B., Brussels, Belgium.

H. BURMEISTER, I. DANILCHENKO***, D. HAIDT, P. JOBIN, C. MATTEUZZI, P. MUSSET K. MYKLEBOST, J.B.M. PATTISON, D.H. PERKINS, D.J. PITTUCK, F. ROMANO and D. WALDREN
CERN, Geneva, Switzerland.

A. BLONDEL, V. BRISSON, B. DEGRANGE, T. FRANCOIS, M. HAGUENAUER+, U. NGUYEN-KHAC, P. PETIAU and P. VAN DAM++
Laboratoire de Physique Nucléaire des Hautes Energies, Ecole Polytechnique, Palaiseau, France.

E. BELLOTTI, S. BONETTI, D. CAVALLI, E. FIORINI, A. PULLIA and M. ROLLIER
Istituto di Fisica dell'Università, Milano and I.N.F.N., Milano, Italy.

B. AUBERT+++, D. BLUM, L.M. CHOUNET, P. HEUSSE, M. JAFFRE, L. JAUNEAU, C. LONGUEMARE, A.M. LUTZ, C. PASCAUD and J.P. VIALLE+
Laboratoire de l'Accélérateur Linéaire, Orsay, France.

F.W. BULLOCK, M.J. ESTEN, T.W. JONES, A.G. MICHETTE°, G. MYATT°° and A.J. SEGAR°°°
University College, London, England.

---

* Chercheur agréé de l'Institut Inter-Univ. des Sciences Nucl., Belgique.
** Vorser I.I.K.W. België.
*** Now at Serpukhov, and IHEP, USSR.
\+ Now at CERN.
++ Also at NIKHEF, Amsterdam, Netherland.
+++ Now at L.A.P.P., Annecy, France.
o Now at Rutherford Laboratory, Rutherford, England.
oo Also at Oxford University, Oxford, England.
ooo Supported by Science Research Council Studentship.

CM/mm

CERN/EP/PHYS 77-2

ABSTRACT:

New results are presented of an analysis of pictures taken during an exposure of Gargamelle to the CERN ν beam in 1975. In addition to three $\nu_\mu + N \to \mu^- + e^+ + V^o$ + hadrons events previously reported, an excess is found of events of the type $\nu_\mu + N \to \mu^- + e^+$ + hadrons without V^o. An analysis of strange particle production in charged current events suggests a possible violation of the $\Delta S = \Delta Q$ rule. Interpreted in terms of charm production, the data permit an estimate of branching ratios and production rate of charmed particles. A limit is also placed on charmed particle production by neutral currents.

A search has been made for semi-leptonic and hadronic decays of charmed particles produced in neutrino interactions observed in Gargamelle filled with heavy freon and exposed to the CERN neutrino wide-band beam peaking at 2 GeV (1).

Within the framework of present theories (2), charmed particles can be singly produced in charged current neutrino interactions and their subsequent decay is expected to lead to final states involving strange particles. If the decay is semi-leptonic, the final state involves also two leptons of opposite charge:

a) $\nu_\mu + N \to \mu^- + C + \text{hadrons}$
$\quad\quad\quad\quad\quad\quad\hookrightarrow e^+ (\mu^+) + \nu + \text{hadrons } (S = -1)$

If the charmed particle decays hadronically, an apparent violation of the $\Delta S = \Delta Q$ rule is expected:

b) $\nu_\mu + N \to \mu^- + C + \text{hadrons}$
$\quad\quad\quad\quad\quad\quad\hookrightarrow \text{hadrons } (S = -1)$

In the present experiment two independent but concurrent scans of the films were made: one for neutral strange particles decaying via their charged mode (V^o) and the other for events containing electrons of either charge and/or e^+e^- pairs whose vertices are close to the neutrino interaction point. The short radiation length of heavy freon (11 cm) ensures excellent electron identification, therefore the dilepton states searched for are of the type $e\mu$. The films were doubly scanned and all the events inside a 3 m^3 fiducial volume were then carefully checked. For the analysis, only electrons of unambiguous charge and showing at least one materialized Bremmstrahlung γ-ray were retained. The electron had to be attached to the neutrino vertex and its energy had to be greater than 200 MeV. To avoid confusion with γ-rays, it was also required that the electron appears clearly as a single track for a distance in space of 2.5 cm before shower development. Hence genuine positrons producing a δ-ray of energy greater than 6 MeV within that range have been reclassified as γ-rays. This loss of signal, averaged over the observed positron energy was estimated to be of the order of 15%. The scanning efficiencies for electrons and positrons so selected and for V^o particles were found to be (97 ± 2)% and (98 ± 2)%, respectively. All events with V^o candidates were measured and carefully scrutinized for the presence of another strange particle (e.g. K^+ meson decaying at rest). The final V^o particle selection was made by a 3C fit whose efficiency was estimated to be larger than 93%. In addition, to get a uniform scanning efficiency for V^o's, the distance between the neutrino vertex and the decay point had to be greater than 1 cm in space, and, to reduce neutron background, the time of flight had to be shorter than 3 mean lifetimes. Within these cuts, the remaining neutron background in the Λ sample was estimated to be 4%. The Λ^o and K^o detection efficiencies were found to be (49 ± 2)% and (23 ± 3)% respectively. For the analysis only those events with a μ^- candidate (CC events), i.e. a negative particle decaying or stopping inside the chamber or leaving it without interacting, were accepted for which the total visible energy is greater than 1 GeV and the total longitudinal momentum exceeds 0.6 GeV/c. The procedure described above has been applied to a sample of pictures taken using the booster facilities and corresponding to about 32 000 CC events (sample 1). In addition, $\mu^- e^+ V^o$ events were searched for in previous Gargamelle runs(3), corresponding to about 9000 CC events (sample 2). Preliminary results of this experiment were reported in ref. (4).

Leptonic decay of charmed particles. The number of events relevant to the present analysis are displayed in table I. Three unambiguous $\mu^- e^+ V^o$ events were identified in the total sample of pictures. In addition, in sample 1 only, there were 17 $\mu^- e^+$. The last three channels in the table will be considered for the sake of checking the background calculations.

The major sources of background simulating dilepton events are:
(a) CC events containing an asymmetric Dalitz pair or an asymmetric γ-ray pair converting close to the neutrino vertex and thus simulating a positron or an electron attached to the vertex. The fraction of γ-rays

with energy greater than 200 MeV in which either the positron or the electron has retained all the energy, has been determined in the present experimental conditions to be $\alpha^+ = (1.5 \pm 0.4)\%$ and $\alpha^- = (4.4 \pm 0.6)\%$ respectively. The probability P_m that a γ-ray appears to be attached to the neutrino vertex either because it is a Dalitz pair or because of a close materialization was found to be $(4.0 \pm 0.6)\%$. These values agree with those calculated from QED, if the same cuts are applied. The number of background events expected from this source is given in table I for the different topologies. For the $\mu^- e^+ V^0$ and $\mu^- e^- V^0$ channels, the observed γ-ray multiplicity (0.5) in the sample of selected V^0 events was taken into account.

(b) ν_e and $\bar{\nu}_e$ events in which a produced π^- meson simulates a μ^-. Due to the small number of $\bar{\nu}_e$ interactions, this background has been estimated, assuming μ-e universality, from the observation in a separate $\bar{\nu}_\mu$ exposure, of $\bar{\nu}_\mu$ events containing a π^- meson simulating a μ^- associated or not with a V^0 particle. The expected background from $\bar{\nu}_e$ (ν_e) interactions in the final states involving a positron (electron) is then calculated taking account of the $\bar{\nu}_e$ (ν_e) fluxes and the difference in the $\bar{\nu}_e$ (ν_e) energy spectra.

(c) The contribution from leptonic decays of known hadrons was estimated to be negligible.

From table I, it is seen that the number of observed events is compatible with the calculated backgrounds for all channels except for $\mu^- e^+ V^0$ and $\mu^- e^+$ where an excess of events is observed. The probabilities that these events are due to background are 3×10^{-4} and 2×10^{-3}, respectively. It is concluded that the 3 $\mu^- e^+ V^0$ and the excess of (11 ± 5) $\mu^- e^+$ are due to a new phenomenon.

The data also indicate a strong correlation between dileptons and the V^0's; among the 32 000 CC interactions, 192 events were found with at least one V^0 particle satisfying the selection criteria and the probability that the observed rate of V^0 particles in $\mu^- e^+$ events is as low as in CC events, is calculated to be 2×10^{-4}. All 3 V^0 particles of

$\mu^- e^+ V^o$ events satisfy selection criteria for both Λ^o and K^o hypotheses. The mass assignment has been resolved using a maximum likelihood method. It consists of comparing the decay configuration of the V^o with the expected distributions of the decay products of Λ hyperons and K^o mesons and taking into account the time-of-flight in both hypotheses. It is found that the probabilities $P_{i\Lambda}$ for the 3 V^o particles to be respectively 0, 1, 2 or 3 Λ are: $P_{0\Lambda} = (4 \times 10^{-2})\%$, $P_{1\Lambda} = 6\%$, $P_{2\Lambda} = 27\%$ and $P_{3\Lambda} = 67\%$. In the following analysis, the weight corresponding to the maximum likelihood has been assigned to the three events yielding 2.7 Λ^o hyperons and 0.3 K^o mesons. From the detection efficiencies of Λ^o and K^o, 3^{+6}_{-2} $\mu^- e^+$ events are expected with an undetected neutral strange particle. It is worth mentioning that in two $\mu^- e^+$ events without a V^o particle there is an indication for the presence of a strange particle. In one case, there is a possible Λ^o decaying into $n\ \pi^o$ (2 converted γ's) and in the other case a possible K^+ interacting and yielding a K^{o}(*). It is concluded that there exists a strong correlation between the production of lepton pairs of opposite charge ($\mu^- e^+$) and strange particles.

Table II presents some relevant features of the three $\mu^- e^+ V^o$ events; if the source of these events is the production and subsequent semi-leptonic decay of charmed particles, the effective masses $\Lambda\ e^+$ and $K^o\ e^+$ given in table II are lower limits of their masses. The visible hadronic mass W_{vis} and the visible energy E_{vis} of the three events are larger than 2 GeV and 3 GeV respectively. Fig. 1 displays the hadronic mass distribution for all $e^+ \mu^-$ events compared to that corresponding to the CC events. 58% of $e^+ \mu^-$ events have $W_{vis} > 2$ GeV while this fraction is only 15% for charged current interactions. Fig. 2 shows the positron energy plotted versus the muon energy.

From the $\mu^- e^+ V^o$ and $\mu^- e^+$ events, the production rate of charmed particles (reaction a) , of assumed mass M = 2 GeV and decaying semi-leptonically to an electron with energy > 200 MeV, is found to be:

(*) In the usual charm scheme, production of a charmed particle on a quark in the sea may be associated to the production of a strange particle of strangeness +1.

$$\frac{\nu + N \to \mu^- + e^+_{E>200} + \text{anything}}{(\nu + N \to \mu^- + \text{anything})_{W>M}} \sim \frac{15}{4800} = (.31 \pm .13)\%$$

where the μ^- e^+ events have been corrected for background and signal loss (loss of positrons and scanning efficiency).

Search for a violation of $\Delta S = \Delta Q$ rule. Using a sample of CC events in which associated strange particle production is identified and the detection efficiencies for K^+ and K^o, it can be verified whether or not the number of events with a Λ ($\nu + N \to \mu^- + \Lambda^o$ + hadrons) is compatible with associated production of strange particles. In the sample of 205 V^o's satisfying selection criteria, 94 are unambiguous Λ's, 54 are unambiguous K^o's and 57 are ambiguous. The maximum likelihood method outlined above permits an assignment for these ambiguous V^o's leading to (51 ± 1.5) Λ's and (6 ± 1.5) K^o's. The sample, after neutron background subtraction is then: 106 single Λ's, 22 $\Lambda^o K^+$, 10 $K^o \Lambda^o$, 1 $K^+K^o\Lambda^o$, 45 K^o, 2 K^oK^o and 0 K^+K^o. Only those K^+'s which decay at rest without a previous interaction have been selected for this analysis. The K^+ detection efficiency was calculated by a Monte-Carlo[5] to be (37 ± 5)%. For that calculation, the same energy spectrum was assumed for positive and neutral kaons. This assumption on which the results are strictly dependent, is supported by the fact that the spectrum of all positive interacting and leaving particles does not extend beyond that of the K^o. On the basis of detection efficiencies and numbers of observed events, (64 ± 18) single Λ's are expected. These are compared with the 106 observed events, showing an excess of (42 ± 20) events. Such an excess together with the observation of μ^- e^+ V^o events might be explained by the production of a charmed baryon. Adopting this hypothesis, the probability distribution for the semi-leptonic branching ratio can be estimated. At 68% C.L., its mean value is:

$$\text{Br}\ \frac{C \to (\Lambda e^+ \nu + \ldots) + (\Lambda \mu^+ \nu + \ldots)}{C \to \Lambda + \text{anything}} = (15\ ^{+18}_{-7})\% \quad E_{e^+,\mu^+} > 200\ \text{MeV}$$

assuming μ-e universality and normalizing the Λ sample to the total statistics (sample 1 + 2). The production rate for charmed baryons, after correction for

Λ detection efficiency, in events with hadronic mass greater than 2 GeV is found to be:

$$\frac{\nu + N \to \mu^- + C + \text{hadrons}}{(\nu + N \to \mu^- + \text{anything})}_{W>2GeV} \times Br \frac{C \to \Lambda^0 + \text{anything}}{C \to \text{anything}} = \frac{86}{4800} \sim (2 \pm 1)\%$$

Charm production by neutral currents. A limit on charm production in neutral current interactions has been obtained by considering the four events with e^+ + hadrons observed in this experiment. A background of (3 ± 1) is expected from ν_e charged current interactions, and (0.7 ± 0.23) events from neutral current interactions having an asymmetric γ attached to the vertex. There is thus no evidence for charm production by neutral currents. Taking the ratio NC/CC given in ref. (6) to calculate the number of neutral current events in sample 1, the limit is (90% C.L.):

$$\frac{\nu N \to \nu + C + \text{anything}}{\nu N \to \nu + \text{anything}}_{E_{had}>1GeV} \times Br \frac{C \to e^+_{E>200MeV}\ \nu_e + \text{anything}}{\text{all}} = \frac{(4-3.7)}{4000} < 1.3 \times 10^{-3}$$

The corresponding ratio in the case of CC events, to which the same cut ($E_{hadrons}$ > 1 GeV) has been applied, is:

$$\frac{\nu N \to \mu^- + C + \text{anything}}{(\nu N \to \mu^- + \text{anything})}_{E_{had}>1GeV} \times Br \frac{C \to e^+_{E>200} + \text{anything}}{C \to \text{anything}} = \frac{15}{16000} = (9 \pm 4) \times 10^{-4}$$

In conclusion, the study of the various channels with one or two charged leptons and with or without strange particles is well explained by the existence of a new type of neutrino reaction leading to the production of a charmed baryon. No such evidence exists in the case of neutral current induced reactions.

We would like to thank the beam, chamber, accelerator, scanning and typing teams for their cooperative work.

REFERENCES

(1) T. Eichten et al., Phys. Letters 46B (1973) 274.

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

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

S.L. Glashow, J. Illiopoulos and L. Maiani, Phys. Review D2 (1970) 1285.

G. Snow, Nucl. Physics B55 (1974) 449.

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

G. Altarelli, N. Cabibbo, L. Maiani 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).

(3) H. Deden et al., Phys. Letters 58B (1975) 361.
Only a part of sample 2 was used for this paper. This sample is not included in the present analysis of V^o's events. The selection criteria and cuts applied to the V^o sample analyzed in this paper are very different from those used in the present one. Thus, a direct statistical extrapolation from one sample to the other is not possible.

(4) J. Blietschau et al., Phys. Letters 60B (1976) 207.

(5) A. Blondel, Thèse 3ème cycle, Université de Paris Sud (1976).

(6) J. Blietschau et al., to be published in Nuclear Physics.

TABLE CAPTIONS

Table I Observed events in each channel and calculated background from different sources.

Table II Characteristics of the 3 ($\mu^- e^+ V^o$ + hadrons) events. The "visible" quantities are calculated taking the Λ hypotheses for the V^o.

TABLE I

Final State	Observed Events	Expected back-ground from $\nu_e/\bar{\nu}_e$	Expected back-ground from γ	Total back-ground
$\mu^- e^+ V^o$ + hadrons	3	$.01 \pm .007$	$.08 \pm .03$	$.09 \pm .03$
$\mu^- e^- V^o$ + hadrons	0	$.2 \pm .14$	$.2 \pm .07$	$.4 \pm .16$
$\mu^- e^+$ + hadrons	17	$.5 \pm .3$	5.6 ± 1.7	6.1 ± 1.8
$\mu^- e^-$ + hadrons	26	9 ± 2	17 ± 3	26 ± 4
e^+ + hadrons	4	3 ± 1	$.7 \pm .23$	3.7 ± 1.0
$e^+ V^o$ + hadrons	0	$.019 \pm .01$	$.025 \pm .008$	$.04 \pm .013$

TABLE II

Topology	$P_{K^o}(\chi^2)$	$P_\Lambda(\chi^2)$	E_{e+} (MeV)	$\Lambda(K^o)$ momentum (GeV)	E_{vis} (GeV)	Y_{vis}	X_{vis}	$M_{e^+\Lambda}$	$M_{e^+K^o}$	W_{vis} (GeV)
$\mu^- e^+ \Lambda (K^o) \pi^{\mp}$ 3p2n	.77	.34	250	2.1(1.8)	3.4	.95	.10	1.25	.65	2.6
$\mu^- e^+ \Lambda (K^o) \pi^+$/p2p	.04	.35	895	1.0(1.4)	3.9	.74	.35	1.93	1.57	2.1
$\mu^- e^+ \Lambda (K^o) \pi^+$/pp	.28	.68	771	3.7(4.8)	5.9	.85	.38	2.00	1.85	2.6

CERN/EP/PHYS 77-2

FIGURE CAPTIONS

Fig. 1 W_{vis} for $\mu^- e^+$ events. Solid line is W_{vis} for all CC events normalized to 20 $\mu^- e^+$ events.

Fig. 2 Plot of E_{e^+} vs E_{μ^-} for $\mu^- e^+$ events (dots), for $\mu^- e^+ V^o$ (crosses) and for $e^- \mu^-$ events (triangles).
It is possible to distinguish two contributions for this latter channel:
one from ν_e events (where $E_{e^-} > E_{\mu^-}$) and the other from asymmetric γ's ($E_{e^-} < E_{\mu^-}$).

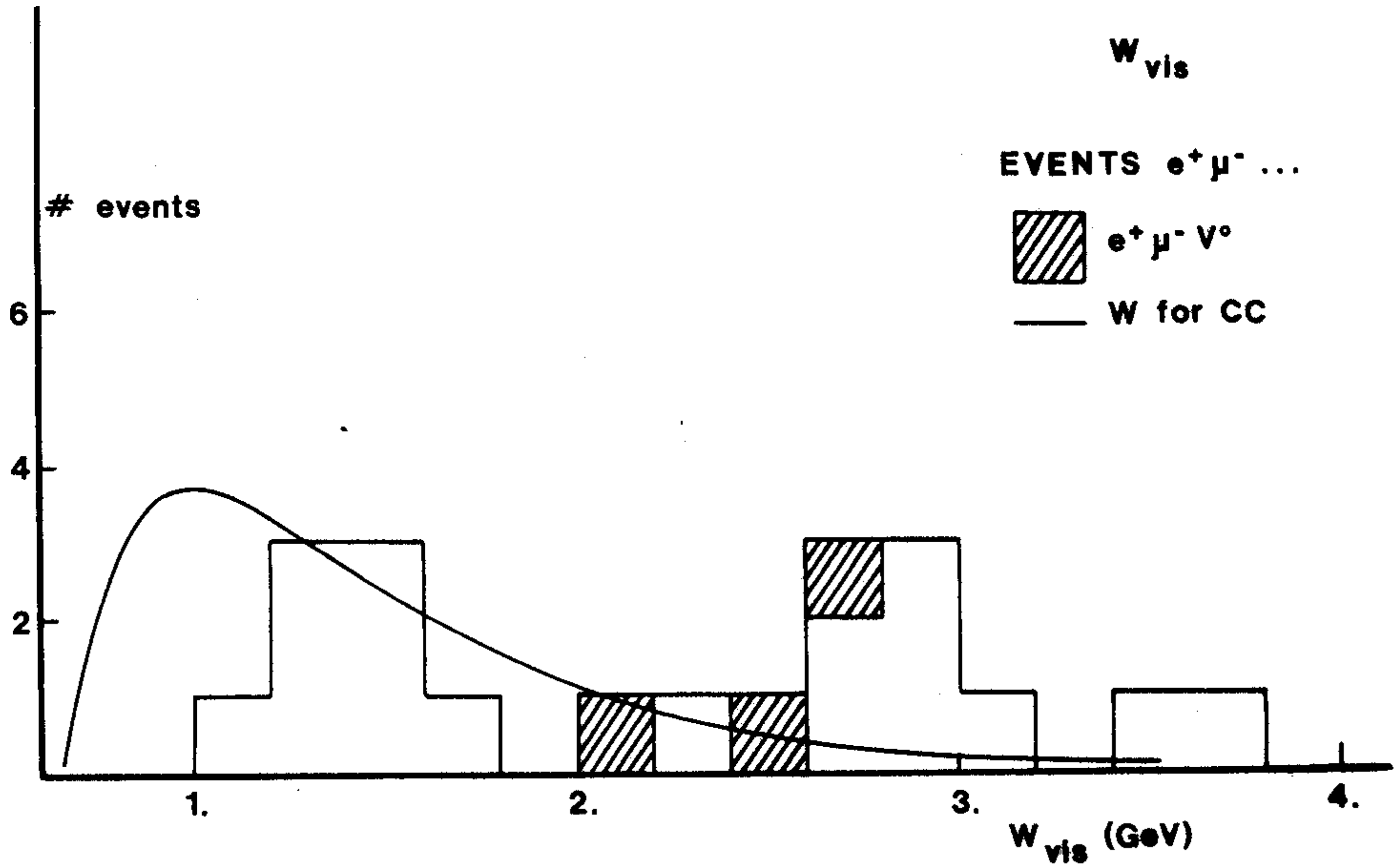
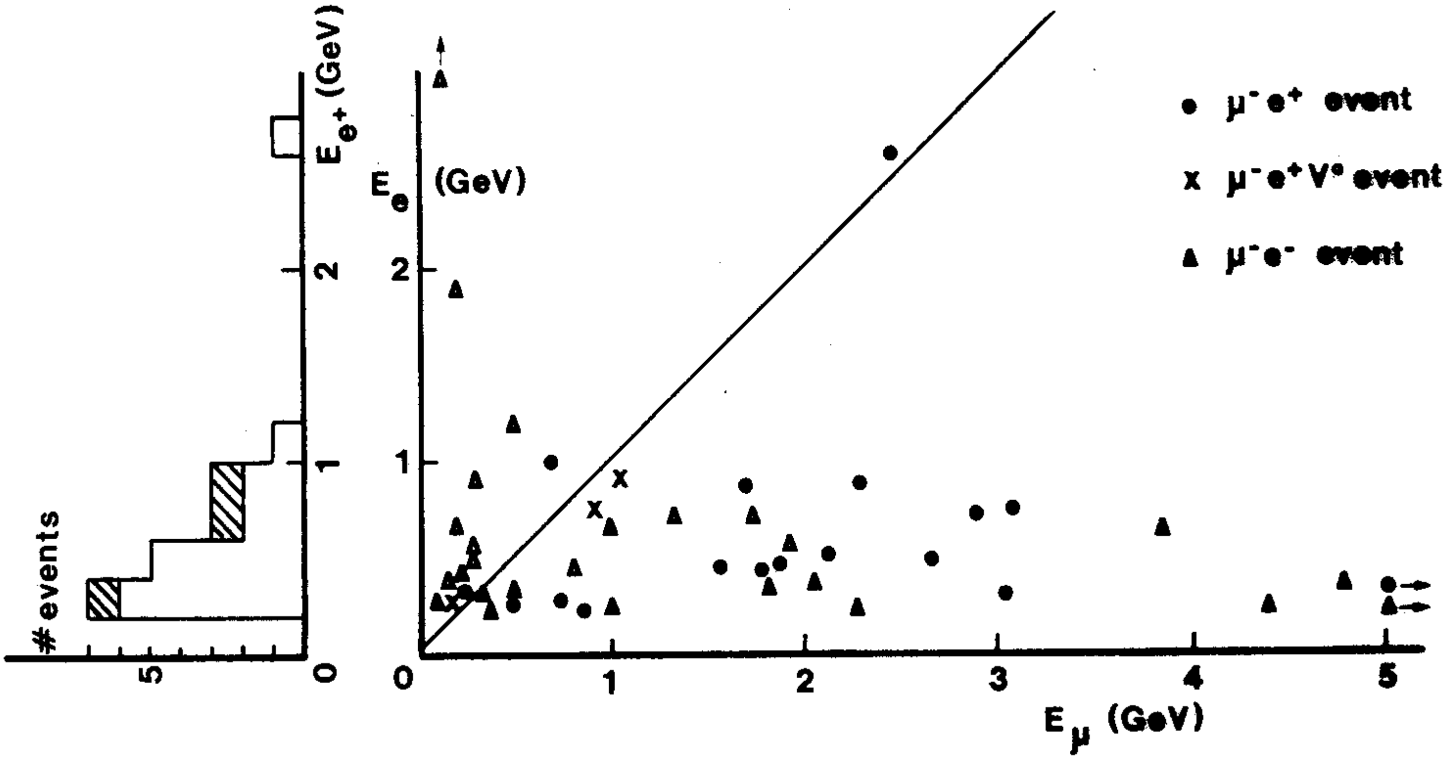


Fig.1



events
5
0
E_{e^+} (GeV)
1
2
E_e (GeV)
0
1
2
3
4
5
E_μ (GeV)
● $\mu^- e^+$ event
x $\mu^- e^+ V^\circ$ event
▲ $\mu^- e^-$ event

Fig. 2