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EVIDENCE FOR A NEUTRINO-INDUCED DILEPTON EVENT IN THE A.N.L. 12-FOOT BUBBLE CHAMBER

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I. Introduction

The observation of dilepton events produced by the interactions of neutrinos or antineutrinos with nuclei has been reported by several experiments[2]. While the most attractive hypothesis for these events involves the decay of a charmed hadron, it has yet to be confirmed. If this hypothesis is indeed correct, then it implies the existence of the two-body reactions

$$\nu p \rightarrow \mu^- B^{++} \qquad (1)$$

or

$$\nu n \rightarrow \mu^- B^+ \qquad (2)$$

where B is a hypothetical baryon having a new quantum number. Although not a dilepton event, an event found at B.N.L.[3] is a candidate for reaction (1). The event was interpreted as the production of the baryon B^{++} with the subsequent decay

$$B^{++} \rightarrow \Lambda^0 \pi^+ \pi^+ \pi^+ \pi^- \qquad (3)$$

which violates the $\Delta S = \Delta Q$ rule.

We have found no strange particle events[4] which were definitely $\Delta S = -\Delta Q$ in the A.N.L.-Purdue ν experiment which utilizes the Argonne National Laboratory 12' bubble chamber. However, in order to search for evidence of a new baryon B^+ (or B^{++}) we have made a systematic study of all events in our sample which contain at least four charged particles. The sample consists of all multiprong events found in the exposures of the bubble chamber to the broad band ν beam at the Z.G.S. It consists of approximately 10^6 pictures

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with deuterium fill and 0.4 x 10^6 with hydrogen. The flux distribution, shown in Fig. 1, peaks at 0.5 GeV but has a tail extending up beyond 6 GeV. In the course of the study an event was found which is a candidate for the reaction

$$\nu p\ (n_s) \rightarrow \mu^- p \pi^+ \pi^- \pi^o e^+ \nu_e\ (n_s). \qquad (4)$$

The bulk of this report will concern that event.

II. The Event

The event, shown in Fig. 2, has five charged prongs and an associated gamma ray (not shown due to its distance from the vertex). The particles are all uniquely identified by their characteristic tracks except for one of the negative tracks (labeled M). They are an e^+ which spirals to rest, a π^- which charge exchanges, a proton which elastically scatters and is also identified by ionization, and a π^+ which decays through the $\pi^+ \rightarrow \mu^+ \rightarrow e^+$ chain. The remaining track which we will name the mystery track M may be a μ^-, e^- or π^-. The information contained in its bubble pattern is not sufficient to resolve the mass ambiguity. Depending on whether the track is a μ^-, e^- or π^-, the event is either an example of dilepton production, a neutral current interaction, or an $\bar{\nu}_e$ charged current interaction, respectively.

Table I shows the measured momentum components for each of the tracks as well as the components of the total visible momentum. The total visible momentum lies along the neutrino beam direction (the x-axis) within about two degrees.

III. Multipion Production in General

Before discussing in detail the multipion production processes that could simulate dilepton production, we shall make some general comments about multipion production in our experiment. We find approximately 230 events in the experiment with neutrino energies greater than 1.74 GeV/c, which is the minimum possible momentum of the neutrino that produced the dilepton candidate. Hence finding one dilepton event is not inconsistent with the approximate 1% rate indicated in other experiments.

We have studied or searched for the following multipion production reactions:[5]

$$\begin{aligned} \nu n\ (p_s) &\to \mu^-\pi^+\pi^- p\ (p_s) && \text{21 events} \\ \nu n\ (p_s) &\to \mu^-\pi^+\pi^- p\pi^o\ (p_s) && \text{8 events} \\ \nu n\ (p_s) &\to \mu^-\pi^+\pi^+\pi^- n\ (p_s) && \text{4 events} \end{aligned} \qquad (5)$$

and

$$\begin{aligned} \nu p\ (n_s) &\to \mu^-\pi^+\pi^+\pi^- p\ (n_s) && \text{12 events} \\ \nu p\ (n_s) &\to \mu^-\pi^+\pi^+\pi^- p\pi^o\ (n_s) && \text{3 events} \\ \nu p\ (n_s) &\to \mu^-\pi^+\pi^+\pi^+\pi^- n\ (n_s) && \text{(no events)} \end{aligned} \qquad (6)$$

For these events the kinematic variables are particularly well measured.

Fig. 3 shows the distributions of these events in neutrino energy E_ν, hadronic mass W, x, and y. The tendency toward small x and large y is due to the fact that the multipion events tend to be produced near threshold. On each plot the dilepton candidate is indicated. Its extreme values of x and y suggest that it involves production near threshold.

IV. Possible Alternate Interpretations of the Event

A. Charged-Current ν_μ Interaction

If the event is induced by a ν_μ via the charged current, then the mystery track M is a μ^-. Consequently, if the e^+ is half of an asymmetric Dalitz pair, then the e^- must have too low a momentum to be visible. A conservative estimate based on a study of Compton electrons indicates that the e^- momentum must be less than or equal to 2 MeV/c. With this momentum limit on the hypothetical e^- we find that the event must contain at least $2\pi^0$ in order to have produced both an asymmetric Dalitz pair and the γ ray which converted in the deuterium. Consequently, the simplest ν_μ charged-current reaction to have produced the event is

$$\nu n\ (p_s) \rightarrow \mu^- p\pi^+\pi^-\pi^0\pi^0\ (p_s). \tag{7}$$

On the basis of observing a sum of three events in the four-pion channels

$$\begin{aligned} \nu p &\rightarrow \mu^- p\pi^+\pi^+\pi^-\pi^0 \\ \nu p &\rightarrow \mu^- n\pi^+\pi^+\pi^+\pi^- \end{aligned} \tag{8}$$

we guess an equal number in reaction (7). Taking into account the 1.17% probability of a Dalitz decay and the 1.5% probability of the electron having less than 2 MeV/c, we find that we would expect this process to contribute $\sim 1.2 \times 10^{-3}$ events.

B. Neutral Current ν_μ Interaction

If the event were induced by a ν_μ via the weak neutral current, then the mystery track would be an e^-, The e^+e^- effective mass would then be 40 MeV, and the probability that this or a higher mass occurs in a Dalitz decay is about 10%. Combining these two tracks with the externally converted γ, one finds an effective mass of 332 MeV/c^2, requiring the production of at least $2\pi^0$'s. The required reaction is then

$$\nu p\ (n_s) \rightarrow \nu p\pi^+\pi^-\pi^0\pi^0\ (n_s). \tag{9}$$

Based on the three charged-current four-pion events found in reaction (8), we might expect $\sim$ 20% as many due to the neutral current. Folding in the Dalitz decay probability and the probability of a 40 MeV/c^2 or higher mass, we estimate that we should expect $\sim 1.5 \times 10^{-3}$ events.

C. Charged-Current $\bar{\nu}_e$ Interaction

The relative flux for $\bar{\nu}_e$ and ν_μ at 1.74 GeV/c (the component of the visible momentum along the beam axis) is 2×10^{-3}. In addition, one expects the $y = (E_{\nu_e} - E_{e^+})/E_{\nu_e}$ distribution to fall with y and be quite small at $y = 0.98$ where the event occurs. The combination of these factors makes this hypothesis highly unlikely.

D. Other Processes

If the event were neutron-induced by the reaction

$$np\ (n_s) \rightarrow np\pi^+\pi^-\pi^o\pi^o\ (n_s) \qquad (10)$$

it would look similar to the neutral current reaction (9). Based on our measured neutron flux[6] and angular distribution we expect $< 10^{-4}$ events.

If the e^+ were due to the decay of a K_L^o

$$K_L^o \rightarrow \pi^- e^+ \nu \qquad (11)$$

the decay would need to occur within about 2 mm of the vertex to be undetected. Of the six strange particles observed in the experiment, each contains a charged or neutral K. For the five events in which the detection efficiency does not bias the momentum determination, the average K momentum is 575 MeV/c. This corresponds to $\beta\gamma c\tau = 18$ m and a probability of a 2 mm or smaller decay being less than $\sim 10^{-4}$.

The 2 mm limit also eliminates the decay of an extremely low momentum π^+ as the source of the e^+, since the μ^+ in a $\pi^+ \rightarrow \mu^+ \rightarrow e^+$ decay chain has a one cm. range.

V. Estimating the Mass of the Produced System

Assuming that the event is actually an example of dilepton production, we now attempt to estimate the mass of the baryonic system recoiling against the μ^-. The total visible final state momentum being along the neutrino beam direction implies that if there are neutral (unseen) particles in the final state their total momentum must also lie along the beam direction or be small. If one interprets the event as being due to reaction (4), it must contain an unseen ν_e and unseen γ. Consequently, unless small, the sum of their momentum must lie along the beam direction.

Since the neutrino is massless, energy conservation implies

$$\Sigma P_x + m_p = P_\nu + m_p = E \qquad (12)$$

where ΣP_x is the sum of the components of the laboratory momenta of the final state particles along the neutrino beam direction (x), m_p is the proton mass, P_ν is the total laboratory momentum (and energy) of the incident neutrino, and E is the total final state laboratory energy. Hence if there were no invisible particles in the final state or they had negligible energy, we would find equation (12) satisfied by the visible tracks. Since the energy of an invisible particle is greater than or equal to its x component of momentum, equation (12) becomes the following inequality in the case of missing particles:

$$\Sigma P_x^{vis} + m_p \geq E_{vis} \qquad (13)$$

where ΣP_x^{vis} and E_{vis} refer to visible particles in the final state.

In the event being discussed $E_{vis} = 2.74$ GeV and $\Sigma P_x^{vis} + m_p = 2.68$ GeV, and equation (12) is essentially satisfied. The fact that the unbalance of ~ 60 MeV violates relation (13) indicates that it should be ascribed to the Fermi motion of the target proton in the deuteron rather than missing particles.

Now consider adding the missing γ and ν_e to the final state. To maintain the satisfaction of equation (12) and the transverse momentum balance, each particle may either have negligible momentum or have its total momentum point along the beam direction. A massive particle such as a $\overline{K^o}$ could only be present if its total momentum is along the beam direction, and it is highly relativistic ($p_x \sim E$).

We may now consider the possibility that this event is due to an alternate decay mode of the new baryonic state indicated by the B.N.L. event, i.e.

$$B^{++} \rightarrow p\pi^+\pi^-\pi^o e^+\nu_e. \qquad (14)$$

The mass of the visible particles $M(p\pi^+\pi^-\gamma e^+)$ equals 1.94 GeV/c^2. If one adds an invisible γ in the beam direction with the proper momentum to make a π^o (70 MeV/c), it only raises the mass by about 30 MeV/c^2 to 1.97 GeV/c^2.

For this event to be compatible with the decay via reaction (14) of a particle with the mass 2.425 GeV/c^2, as found in the B.N.L. event, it would require the missing neutrino to both have high energy ($\sim$ 1 GeV) and be pointing along the beam direction. Neither of these conditions would be likely to occur in a random sample of such decays. The mass of the baryonic system is much more likely to be $\sim$ 2 GeV. A Monte Carlo study of the decay process (14) of a 2 GeV/c^2 baryon shows that the most probable momentum for the e^+ or ν_e to be $\sim$ 70 MeV/c. Consequently, the observed e^+ momentum of 41 MeV/c is not surprisingly low; nor is it surprising that the visible energy and momentum balance is so good.

The two-body effective masses of the observed tracks are not consistent with the decay of a K^o, Λ^o, or Σ^+ with very short decay length and hence there is no evidence of strangeness in the event.

VI. Conclusion

The event we have found is clearly unusual if one tries to explain it in terms of normal neutrino interactions. On the other hand, if it is an example of dilepton production, it does occur at the expected rate $\sim 10^{-2}$ of single lepton production. If it is due to the weak decay of a new baryon, the baryon mass appears to be near 2 GeV/c^2 and unlikely to be as high as 2.4 GeV/c^2.

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References

1. V. E. Barnes, D. D. Carmony, E. Fernandez, and A. F. Garfinkel, Purdue; M. Derrick, T. Dombeck, L. G. Hyman, B. Musgrave, P. Schreiner, R. Singer, and M. Szczekowski, Argonne National Laboratory.

2. A. Benvenuti et al., Phys. Rev. Lett. 35, 1249 (1975); J. Blietschau et al., Phys. Lett. 60B, 207 (1976); J. von Krogh et al., Phys. Rev. Lett. 36, 710 (1976); B. C. Barish et al., Phys. Rev. Lett. 36, 939 (1976).

3. E. G. Cazzoli et al., Phys. Rev. Lett. 34, 1125 (1975).

4. S. J. Barish et al., Phys. Rev. Lett. 33, 1446 (1974).

5. Our single-pion reactions were discussed in S. J. Barish et al., Phys. Rev. Lett. 36, 179 (1976).

6. The neutron background is discussed in S. J. Barish et al., Phys. Rev. Lett. 33, 448 (1974).

Table I

(the measured particles)

Particle	p_x (GeV/c)	p_y (GeV/c)	p_z (GeV/c)	E (GeV)
M (as μ^-)	.150	-.059	-.125	.229
π^-	.230	-.176	.060	.327
e^+	.036	-.017	-.008	.040
π^+	.036	-.082	.022	.168
p	.840	.605	-.095	1.401
γ	.450	-.328	.157	.578
Total	1.742	-.057	.011	2.743

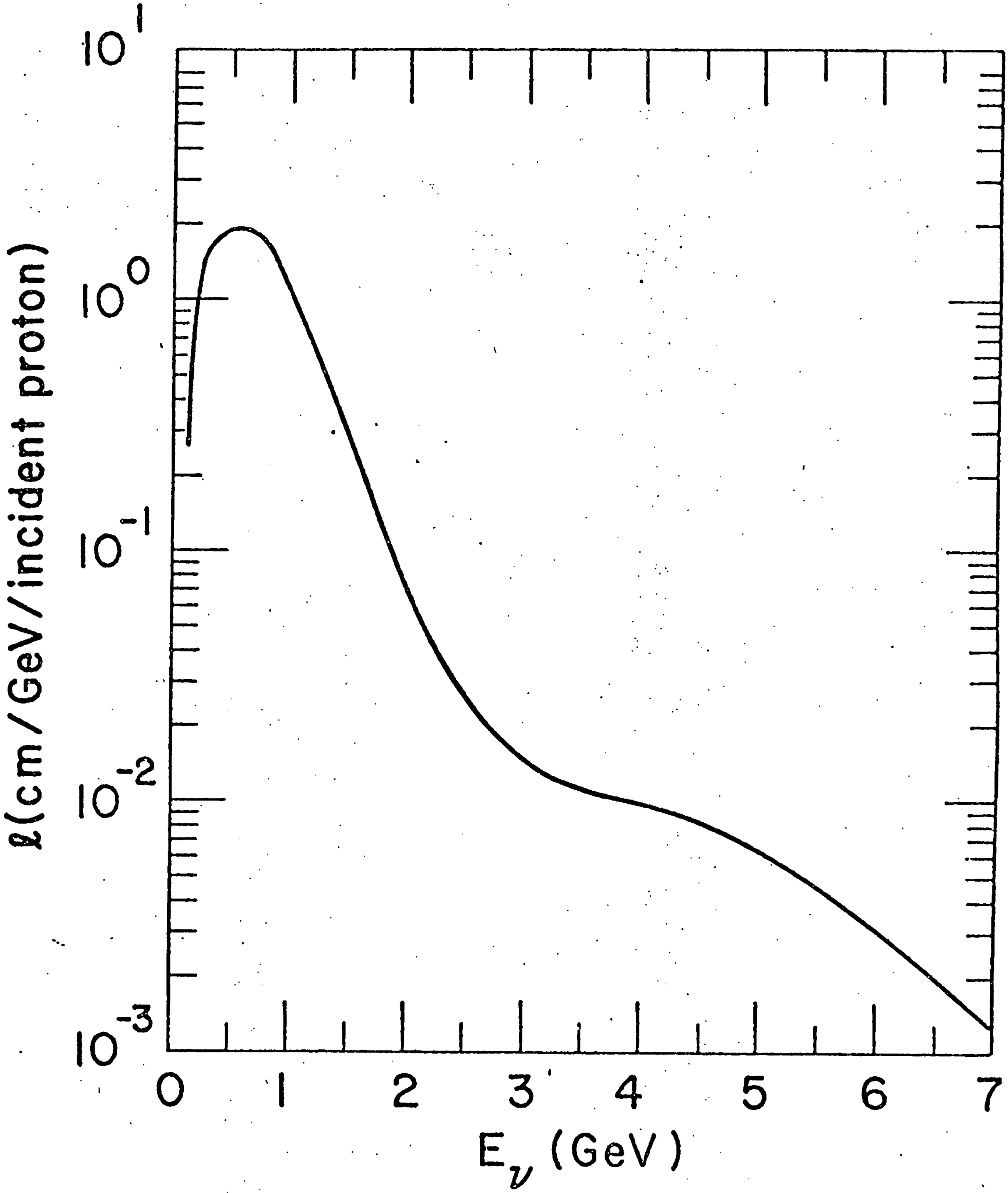
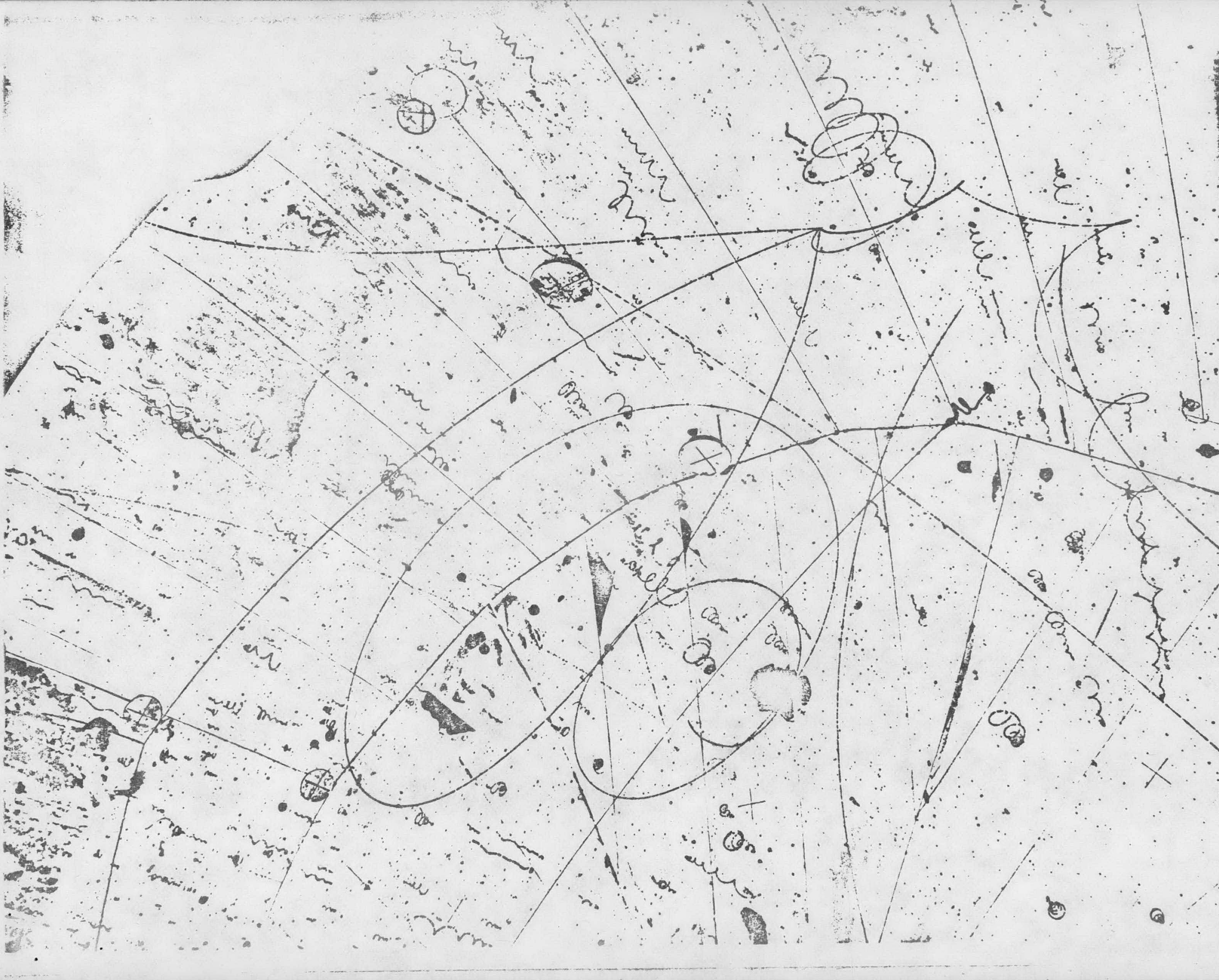


Fig. 1

Neutrino Spectrum



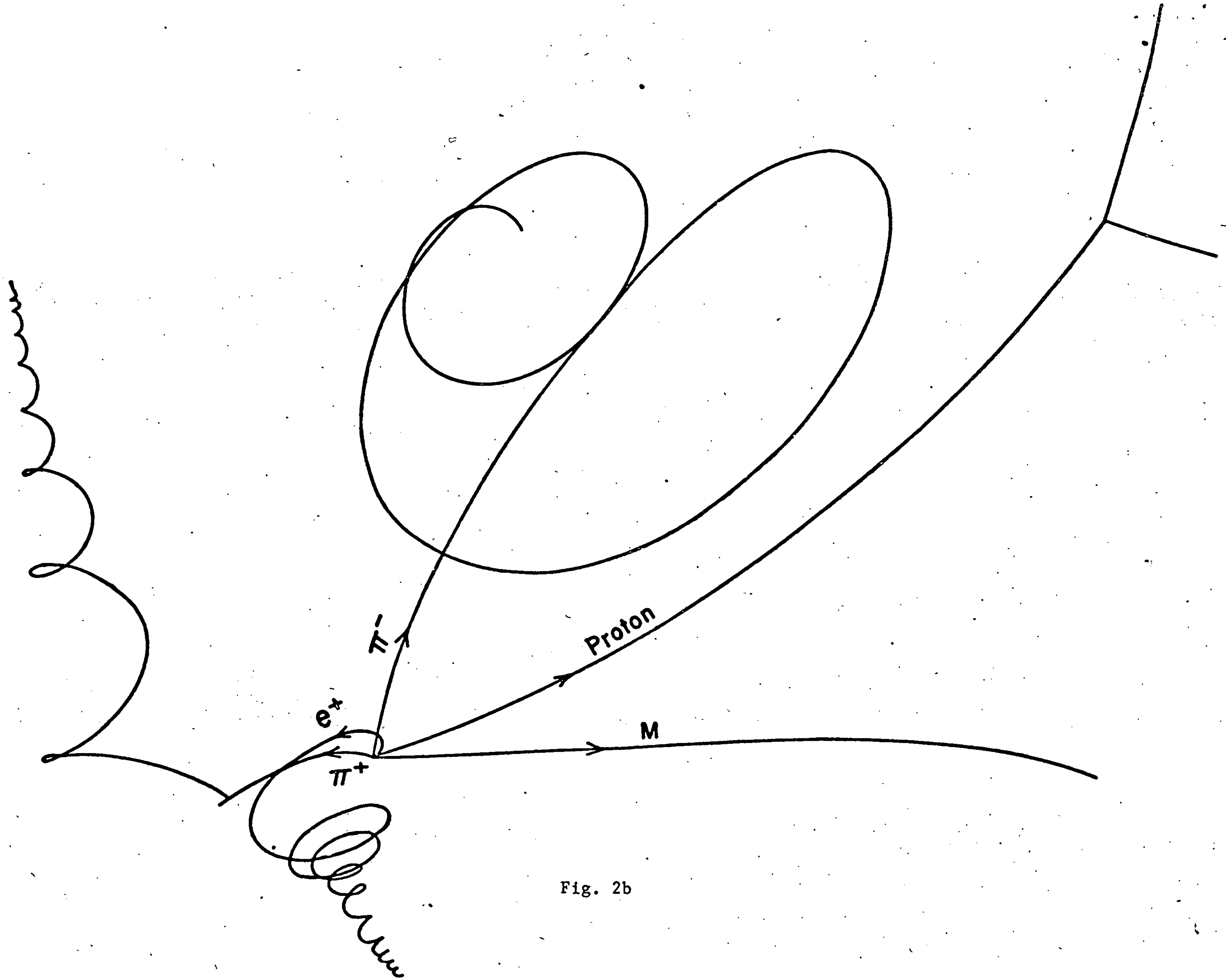


Fig. 2b

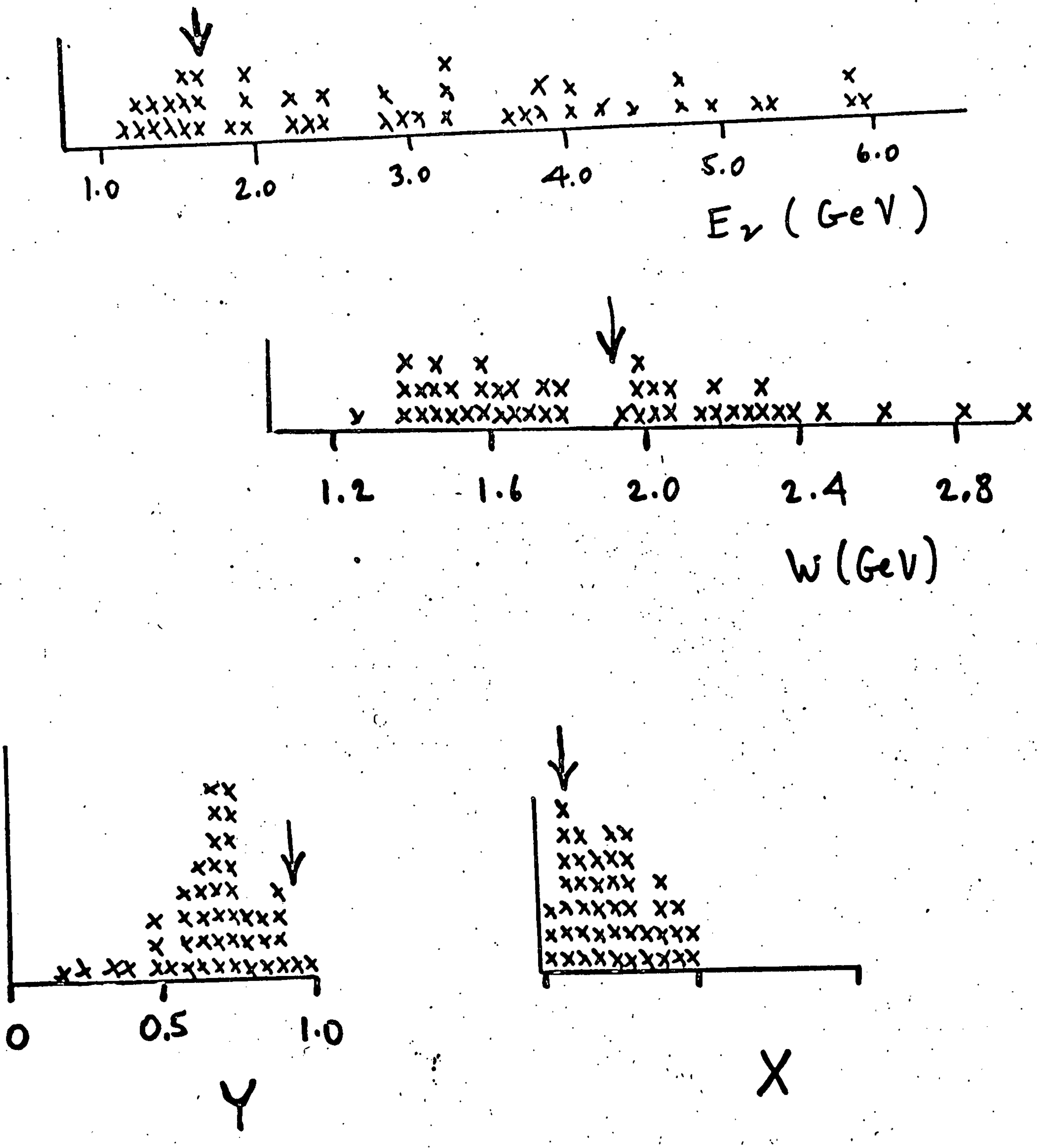


Fig. 3

Multipion Distributions