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OBSERVATION OF AN EXCESS OF ν_e, $\bar{\nu}_e$ EVENTS IN A BEAM DUMP EXPERIMENT AT 400 GEV

Gargamelle Collaboration

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ABSTRACT

A beam dump experiment has been performed at CERN in Gargamelle using the neutrino facility to look for penetrating particles produced either directly in the beam interaction or by prompt decay of new particles. A total of 32 interactions with a visible energy greater than 10 GeV has been found, classified, after corrections, into 18 charged current ν_μ or $\bar{\nu}_\mu$, 5.1 neutral current and 8.9 ν_e or $\bar{\nu}_e$ charged current events. An excess of ν_e events remains after all subtractions from any established sources. Results are presented in terms of the product of the cross section and the leptonic decay branching ratio of the possible source.

This experiment was performed in order to look for neutral penetrating particles either produced directly at the target or resulting from the decay of short-lived parents such as heavy leptons or hadrons with new flavours.

The 400 GeV extracted proton beam from the CERN SPS, transported in a vacuum pipe, was dumped on to a target consisting of a copper cylinder of 27 cm diameter and 2 m length, immediately followed by a 40 x 40 cm^2 iron block of length 80 cm. The dumping of the hadron cascade in the target reduced the normal neutrino flux by a factor of about 2000. The detector was the heavy liquid bubble chamber, Gargamelle, filled with heavy freon (CF_3Br, radiation length 11 cm, density 1.5 g/cm^3) providing a useful volume of 7 m^3. The chamber, placed 950 m behind the target, was equipped with a two-plane External Muon Identifier (EMI) giving an average muon detection efficiency rising from 0.73 at 10 GeV and reaching 0.98 at 50 GeV neutrino energy. A total of 68 000 pictures was taken, corresponding to 3.5 x 10^{17} protons on the target.

The pictures were scanned twice for all types of interactions. Only events with a visible energy greater than 10 GeV were retained because neutrino flux calculations are unreliable at low energies. These were classified into three categories

(a) events having a muon identified in the EMI (ν_μ or $\bar{\nu}_\mu$ charged current (CC) events);

(b) events having an electromagnetic shower attached to the primary vertex (ν_e or $\bar{\nu}_e$ CC candidates);

(c) events without an electron or identified muon (neutral current (NC) candidates);

No signal for multilepton events was observed.

The number of events are shown in table 1. Owing to the short radiation length, the identification of ν_e and $\bar{\nu}_e$ CC candidates was achieved by simple visual inspection with full efficiency. However, it was not possible in general to determine the sign of the charge of high energy electrons, or to distinguish between electrons and γ-rays attached to the vertex. One of the observed events is shown in fig. 1. The spatial distributions both radially and along the beam axis, are shown in fig. 2 and found to be quite compatible with those of normal neutrinos, as opposed to a possible neutron source. The visible energy distributions for the three classes of events are also shown in fig. 2.

To obtain the numbers of charged current ν_μ, $\bar{\nu}_\mu$, ν_e, $\bar{\nu}_e$ and neutral current events produced, two corrections have to be applied. The sample of NC candidates contains genuine CC events in which the muon has missed the EMI. This correction was calculated assuming normal x and y scaling variable distributions and is 2 ± 1 events. Secondly, some of the events classified as ν_e or $\bar{\nu}_e$ candidates could indeed be NC events in which a γ-ray materialising close to the primary vertex simulates an electron. The probability of attachment, p, has been estimated to be 10 ± 4% using all γ-rays observed in the present sample of events. Taking into account that none of the ν_e or $\bar{\nu}_e$ candidates has an identified muon, the close γ-ray background was calculated by multiplying the number of γ's of energy greater than 5 GeV in NC events by the probability p; it is 0.1 ± 0.1 events. The final sample consists therefore of 18 charged current ν_μ or $\bar{\nu}_\mu$ events, 5.1 neutral current events and 8.9 charged current ν_e or $\bar{\nu}_e$ events (see table 1). By using the measured number of charged current events, the expected number of NC events with hadronic energy greater than 10 GeV, using NC/CC = 0.25 for ν and NC/CC = 0.50 for $\bar{\nu}$, is 6.2 (the two ratios take into account the energy cut). This is consistent with the observed number.

Trimuons and anomalous dimuon events observed in high energy neutrino experiments [1,2,3] might be due to the interaction of a new type of neutrino produced directly at the target [4]. The rate of events due to such particles would be the same in a wide band neutrino beam as in a beam dump experiment. Since no events of the type $\mu\mu$ or μe have been observed, this experiment yields an upper limit for the production of tri-lepton and di-lepton events. The confidence level is shown in fig. 3 as a function of the product of the tri-muon (relative to single muon) rate, r, in ordinary neutrino reactions above 100 GeV and the percentage, s, of tri-leptons due to a new prompt source. For instance, in the present experiment for $r = 5 \times 10^{-4}$ and $s = 0.5$, the expected number of events is 6. The confidence level to observe no events is 2×10^{-3}.

The data from the present experiment can also be used to investigate the proposed existence of axions [5]. These pseudoscalar bosons, coupled semi-weakly to quarks, should be produced and interact with a cross section $R = 10^{-7}$ to 10^{-8} times that of π^0's. In this experiment axion interactions would produce an excess of neutral current-like events. As we have no evidence for such an excess we can set the limit (at 90% C.L.)

$$R \times \sigma_{int} < 2.4 \times 10^{-42}\ \mathrm{cm}^2$$

where σ_{int} is the axion interaction cross section. Taking $\sigma_{int} \sim \sigma_\pi \times R$, we obtain the limit $R \lesssim 10^{-8}$ which is somewhat lower than theoretically expected.

The expected ratio of ν_e and $\bar{\nu}_e$ to ν_μ and $\bar{\nu}_\mu$ events, calculated under the assumption that only pions, kaons and hyperons are produced by the primary beam, is about 6%, which is in evident disagreement with the results. Muon decays, following π or K decay or direct μ production, assumed to be of the order of 10^{-4} relative to π production [6], give a contribution of the order of 1%. The probability that the above sources produced the observed number of electron events is estimated to be less than 5×10^{-5}.

Direct production of heavy leptons, τ, followed by the decay

$$\tau \to \nu_\tau + e + \nu_e$$

is unlikely to account for the observed ν_e and $\bar{\nu}_e$ event rate because of the magnitude of the effect observed, compared to the upper limit of 0.1 nb for the τ production cross section which can be derived from the data of reference [7].

A plausible origin of the large ν_e or $\bar{\nu}_e$ event rate is the strong interaction production of charmed particles in the target by the primary beam. Since charmed particles must be produced in pairs and are expected to have electronic and muonic semi-leptonic decays of similar strength, they generate ν_e, $\bar{\nu}_e$, ν_μ and $\bar{\nu}_\mu$ fluxes of about the same intensity. Thus the inclusion of charmed particles among ν and $\bar{\nu}$ parents is adequate to explain the experimental results. This hypothesis was studied by means of a Monte-Carlo calculation in which charmed D mesons were singly produced following Bourquin and Gaillard [8] and allowed to decay semi-leptonically according to the electron centre of mass spectra measured at SPEAR [9]. Assuming also that the ν_e and $\bar{\nu}_e$ fluxes are equal, the following relation is obtained:

$$\sigma_D \times B_{D \to e^+ + \nu + X} = 32 {}^{+15}_{-10} \ \mu b .$$

In the present experimental conditions no distinction can be made between charmed baryon C and D contributions. It must be emphasized that in this kind of experiment one actually detects neutrinos emitted by D's or C's produced in a relatively small fraction, $\lesssim$ 10%, of the cross section in the fragmentation region. The extrapolation to the total cross section is thus largely model dependent and is particularly sensitive to the assumed longitudinal form of the invariant cross section. The parametrization used above corresponds approximately to a longitudinal dependence of the type $(1 - x_F^{cm})^n$ where x_F^{cm} is the Feynman scaling invariable in the centre of mass and $n \simeq 3$. A variation of n in the interval $1 \leqslant n \leqslant 8$ changes the value of σ B by a factor of two, up or down. The chosen parametrization is the one that best reproduces the observed visible energy distribution. The production of charmed baryons C could also contribute to the observed signal. In that case, the value of the cross section includes the contributions from both C's and D's. The result quoted neglects contributions due to re-interactions of secondary particles. This is justified by the fact that the interactions of ν_μ's coming from pions created in secondary interactions have been calculated to contribute only below 10 GeV energy.

A charm production cross section of this magnitude implies that a substantial fraction of direct lepton production is in fact due to charm decay. This is reasonably consistent with the present experimental situation [10]. On the other hand, it becomes compatible with the limit $\sigma_c \leqslant 1.5$ μb obtained in an emulsion experiment at 300 GeV [11] if the lifetime of charmed particles is $\gtrsim 10^{-12}$ or $\lesssim 10^{-14}$ seconds. In this case only such a cross section would not have been observed in the emulsion experiments.

As a conclusion, the excess of ν_e and $\bar{\nu}_e$ events observed in this experiment can hardly be accounted for by established sources, including recently reported heavy leptons and charmed particles, unless branching ratios, cross sections and lifetimes reported from various experiments or theoretical estimates are not self-consistent.

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TABLE 1 : Event Numbers

	ν_μ or $\bar{\nu}_\mu$ CC			ν_e or $\bar{\nu}_e$ CC	NC
	ν_μ	ν_μ or $\bar{\nu}_\mu$	$\bar{\nu}_\mu$		
Observed events with $E_{vis} > 10$ GeV	12	2	2	9	7
and with $E_{had} > 10$ GeV	8	1	1		
Produced events	18			8.9	5.1

FIGURE CAPTIONS

Fig. 1 Photograph of one electron candidate event.

Fig. 2 (a) Spatial distributions along the beam axis.
(b) Radial distributions in squared distance to the beam axis.
(c) Visible energy distribution.

Fig. 3 Confidence level for tri-leptons induced by neutrinos produced at the target, as a function of the product of the tri-muon relative to single muon rate r and the fraction s of tri-muon due to a new prompt source.

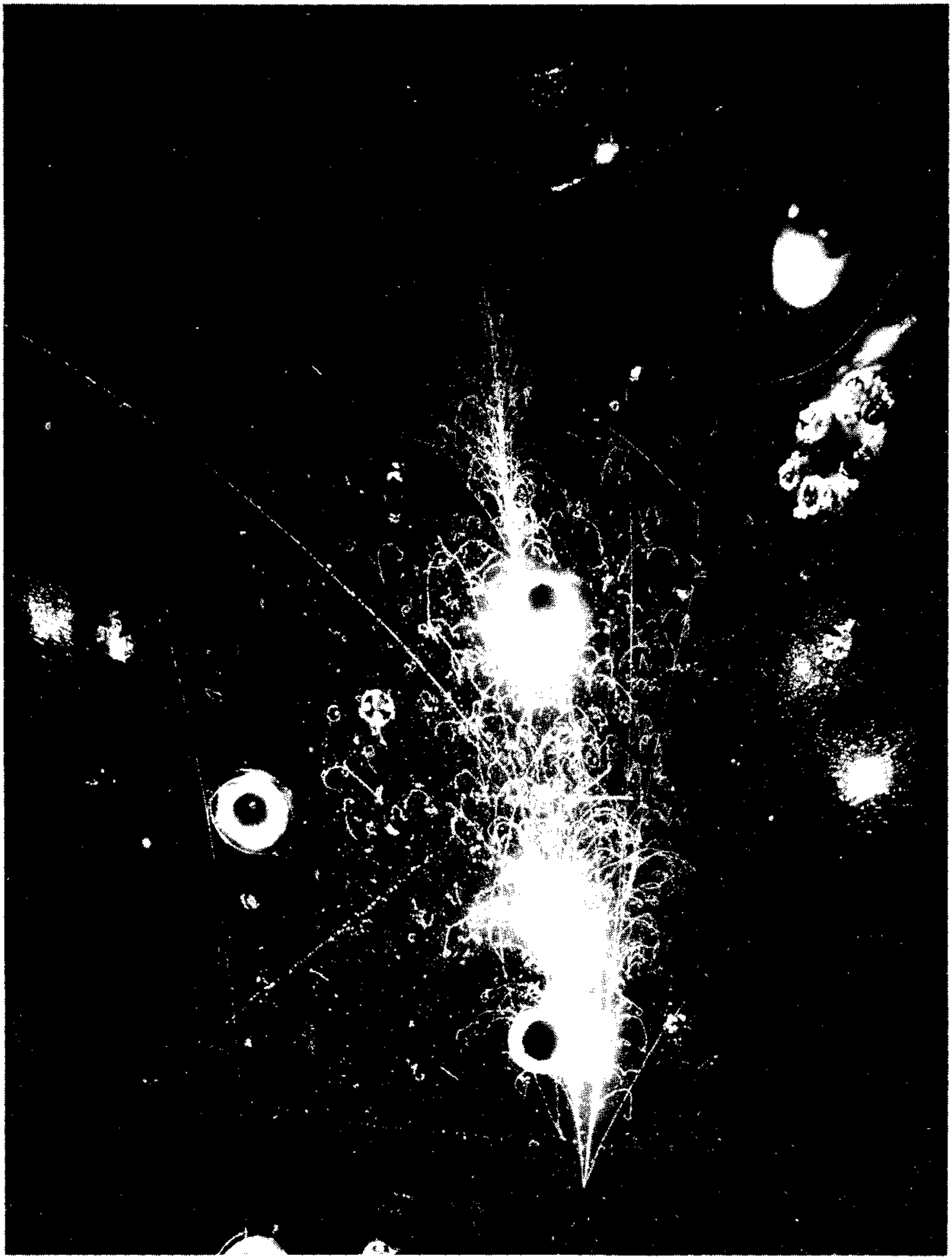
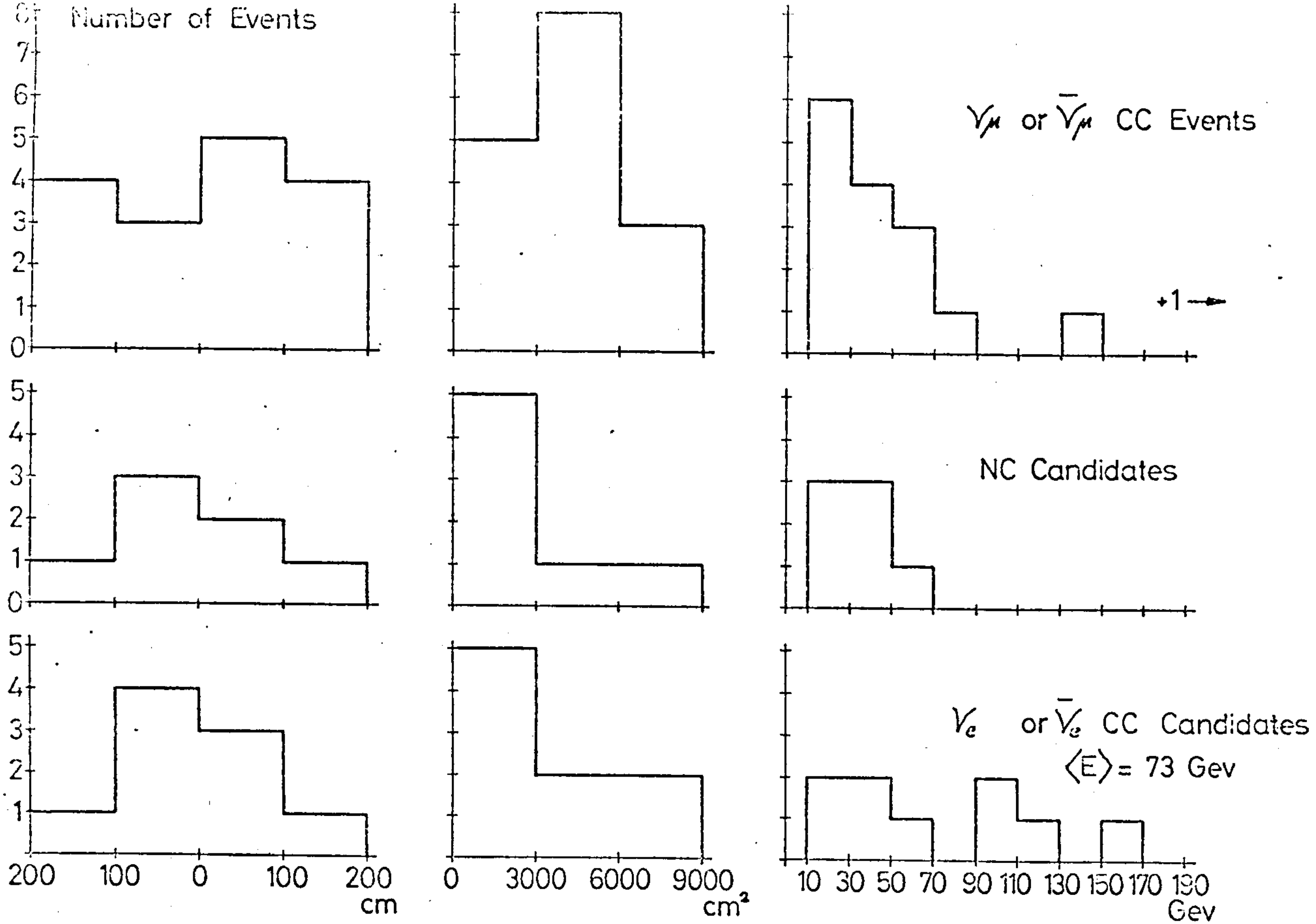


Fig. 1



a) Beam Axis

b) Radial

c) Visible Energy

Fig. 2

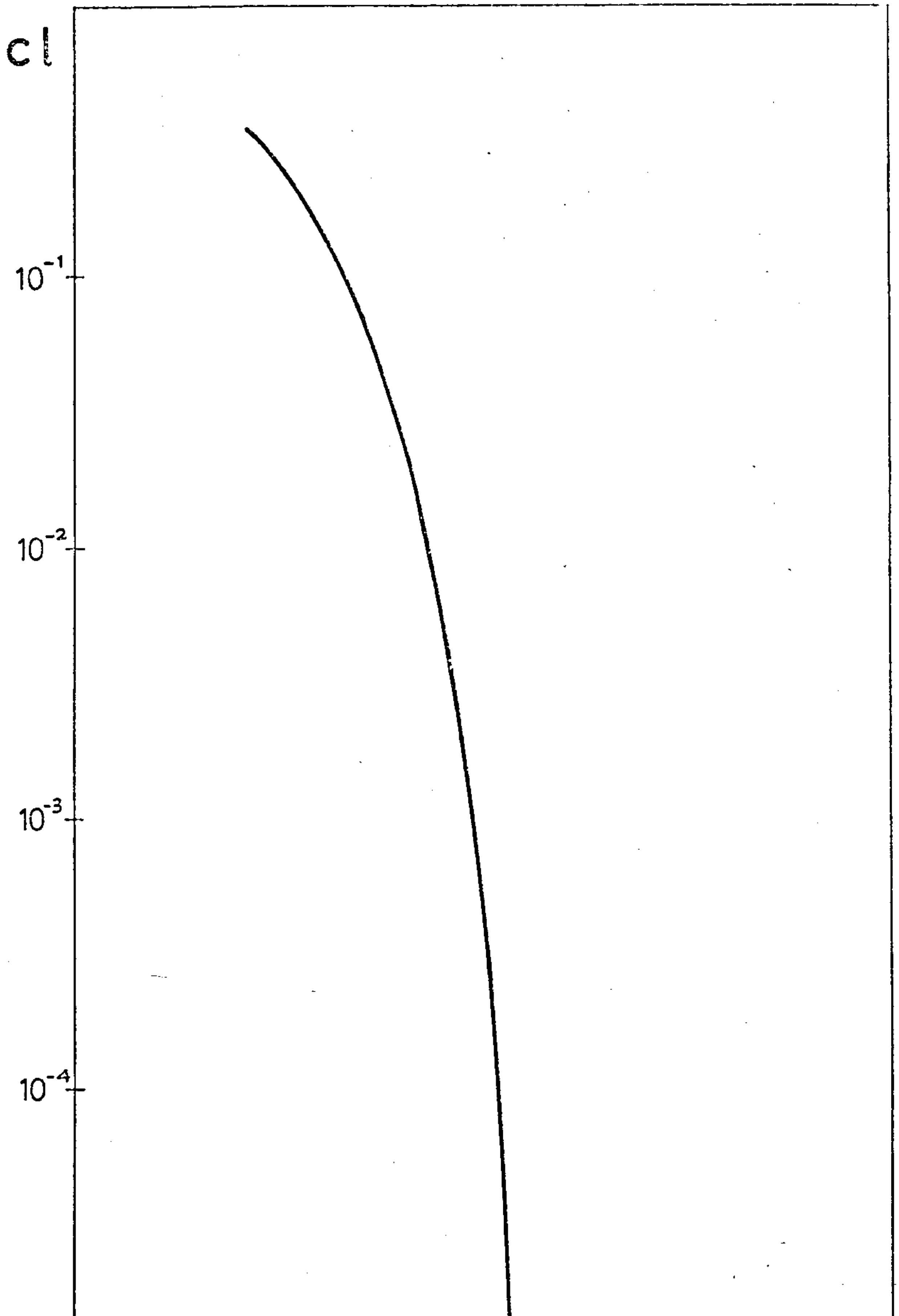


Fig. 3