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SPECTROSCOPY OF NEUTRINO-PRODUCED ELECTRONS

by

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SUMMARY

A comparison is made between two spark chamber counter set-ups for the detection and measurement of neutrino-produced electrons. One is an assembly of thick-plate spark chambers triggered by scintillation counters, the other is a sandwich of flat lead perchlorate Čerenkov counters with thin-plate spark chambers in between. The first set-up measures the electron energy by sampling of the shower, the second one by total absorption. It is concluded that the total absorption method is three to four times as accurate as the sampling. Some technical details are given on an effective 10-ton total absorption set-up.

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I. INTRODUCTION

One of the first questions one hopes to answer in a high-energy neutrino experiment is: whether there are two kinds of neutrinos or whether there is only one$^{1)}$. If the neutrinos from pion decay are different from the neutrinos emitted in nuclear β decay, they can induce inverse pion decay

$$\nu + n \rightarrow p + \mu^- , \qquad (1)$$

but not inverse β decay

$$\nu + n \rightarrow p + e^- . \qquad (2)$$

If there is only one sort of neutrino, the two reactions occur with comparable probability.

Because, in principle, the question can be decided on the basis of one clear event of type (2), a heavy liquid bubble chamber seemed to be particularly suited for this purpose$^{2)}$. The counter arrangements considered so far$^{3)}$ concentrated instead on a systematic study of the muon reaction (1). Unfortunately, as was pointed out by von Dardel$^{4)}$, with the present neutrino fluxes it would take quite a long time until one could hope to see a neutrino event appearing in one of the available bubble chambers of ≈ 0.5 tons weight. It seems worth while, therefore, to consider a multi-ton detector capable of detecting and identifying the electrons from reaction (2) with high efficiency. The difficulty is that one expects electrons to show up even when reaction (2) is forbidden, because of the inelastic process

$$\nu + n \rightarrow p + \mu^- + \pi^0 \qquad (3)$$

(and similar reactions).
For our neutrino energies the contribution from <u>all</u> inelastic channels is estimated to be $\approx 50\%$ of the elastic channel$^{5)}$. For reaction (3) alone one therefore expects $\approx 15\%$ of the elastic channel (1) [or (2)]. If one has a sample of neutrino events of types (1) and (3) one could think of excluding process (2) on

statistical grounds, even if some of the observed events would be compatible with (2). However, the statistical argument is questionable for two reasons.

i) The expected rate of events is low [around 0.05 per ton, elastic channel and day, with the present fluxes 4)]. One is therefore subject to large fluctuations.

ii) The argument rests on the supposition that the cross-sections for (1) and (2) are equal. This may not be true, because apart from kinematical corrections (which are indeed small) there may be a sizeable contribution of induced pseudoscalar interaction in (1) which is missing in (2) 6).

It is therefore essential that the distinction between (2) and (3) (or other confusable reactions) is possible for each event.

It is the purpose of this report to investigate the possibilities of measuring neutrino-produced electrons as accurately as possible (Section II). In conclusion, a 10-ton set-up is proposed which measures the energy of electrons around 500 MeV by total absorption in a series of flat lead-perchlorate counters with an expected accuracy of ≈ 10% (Section III).

II. SHOWER SAMPLING OR TOTAL ABSORPTION?

Because of the detailed information wanted about each event, a pure counter set-up is not sufficient. Instead, one has to use a hodoscope in combination with the counters. At present, the most convenient one seems to be a spark chamber counter combination *). There are two fundamentally different types.

A. The detector mass is concentrated in the chamber; the counters serve only for triggering. This is the construction adopted in Brookhaven 7): sub-units of ≈ 10 Al-plates, 2.5 cm thick, are each followed by a pair of thin plastic counters.

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*) For a discussion, how to tell neutrino events from background, see Ref. 3).

B. The detector mass is concentrated in the counters which measure the dissipated energy. The thin-walled spark chambers serve only as a hodoscope. For the experiment under consideration the counter substance must have short radiation length; high density is desirable. Concentrated lead-perchlorate solution fulfils these requirements:

$$\rho = 2.64\ \text{g/cm}^3,$$
$$X_0 = 4.3\ \text{cm}\ (= 11.3\ \text{g/cm}^2),$$
$$E_{crit} = 21.9\ \text{MeV}.$$

With an arrangement of type A one determines the electron energy by sampling: if the shower propagates in x-direction one measures the electron multiplicity n_e in discrete steps x_i given by the plate thickness d. The electron energy E_0 is then inferred from the total multiplicity

$$N = \sum_i n_e(x_i), \qquad x_{i+1} - x_i = d$$

according to

$$E_0 = \epsilon N$$

with a calibration constant ϵ (which is best determined experimentally).

This method has been applied in cloud chambers[8,9]) with the result that around 500 MeV the E_0 of a single event can be determined with an error around 30% *). Basically the same method was used with counter set-ups by Frisch and co-workers at MIT[10]) and by Hyams' group[11]) at CERN. Their arrangements consisted of alternating metal plates and plastic scintillators. The only difference is that instead of measuring $n_e(x_i)$ directly, they determine the total energy loss of the charged particles present at a thickness x_i (which gives at least the same amount of information

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*) "Error" in this report means throughout: mean square (= "standard") deviation of a single measurement from the true value.

as counting the number of tracks). The response of these set-ups to monoenergetic electrons shows approximately the same large fluctuations as were observed in the cloud chambers (see Fig. 1). Qualitatively this is easy to understand: because a large fraction of the shower energy is absorbed in the plates, a small fluctuation in this amount means a very large one in the small fraction which is actually observed. A quantative interpretation of the measurements on the basis of existing shower theories still seems to encounter some difficulties.

With an arrangement of type B, shower fluctuations are avoided altogether because, in principle, the total energy is absorbed and measured in the counters. What one measures, in fact, is the total path-length of electrons giving Čerenkov light. It is well known that good linearity and energy resolution can be achieved with total absorption Čerenkov counters for electron energies ranging from some hundred MeV[12-14]) up to many GeV[15]).

The accuracy with which the energy of a single electron can be measured is limited by two effects:

i) loss of part of the shower, either because some particles escape or they are absorbed in material outside the counters;

ii) statistical fluctuations in the number of photoelectrons ejected by the Čerenkov light.

For a detector of the proposed size of $45 \times 35 \times 25$ X_0^3, escape losses are negligible. Only 20% of the total mass is not viewed by photo-tubes, which makes fluctuations from the shower development small. The main uncertainty therefore comes from photoelectron statistics. The expected accuracy as a function of electron energy E_0 is given in Fig. 1 for an ideal counter, which is defined by no shower loss and 100% light collection. In calculating the total electron path, use was made of Burmeister's[9]) observation that in lead 80% of the total electron track length L is produced which one would expect according to shower theory approximation B (namely $L = E_0/E_{crit.}$). Another 10% were subtracted in order to account for the lower efficiency for Čerenkov light production towards the end of the electrons' paths. A Čerenkov light output of 200 useful quanta per cm was assumed, and a photo-cathode efficiency of 7%. A more realistic resolution curve is also plotted in Fig. 1. It refers to the conditions expected for the set-up proposed in Section III: 20% shower loss and 30% light collection. The resolution of some existing total absorption counters is shown for comparison. The measured mean square deviations lie well above even the "realistic" curve, mainly because of the insufficient counter sizes.

The experimental data on the different arrangements depending on shower sampling are somewhat confusing. In general, they do not even show the $1/\sqrt{E_0}$ - dependence one would naïvely expect, and the practically energy-independent resolution of the counter of Pugh et al.[10] is indicative of some systematic instrumental effect. If one takes an "uncritical" average over the data, one would conclude that at an electron energy around 500 MeV the proposed large total absorption set-up is about 3 to 4 times better.

The increased accuracy of the electron energy measurement is the only advantage which a type B construction has over a type A one. The measurement of the electron emission angle is in both cases limited by shower fluctuations to an accuracy around ± 10°. As far as the muon reaction (1) is concerned, both arrangements are comparably good. Arrangement A will, in general, be slightly superior in the range measurement of stopped muons, because usually the plate thickness in type A will be smaller than the counter thickness in type B. However, this advantage is purely academic, because in an arrangement permitting the study of the electron production the muons would leave the detector in the majority of cases. The comparison between the arrangements of types A and B can be summarized in two sentences.

i) Both set-ups detect (but do not measure) neutrino-produced muons with comparable efficiency and reliability.

ii) For the measurement of neutrino-produced electrons, arrangement B is ≈ 3 to 4 times better than A, thereby also making the rejection of confusing reactions more reliable.

III. A 10-TON TOTAL ABSORPTION ČERENKOV COUNTER WITH SPARK CHAMBER HODOSCOPE

An arrangement which can be constructed in about half a year's time is sketched in Fig. 2. It is meant to fit into the already existing anticoincidence counter house$^{3)}$ (not drawn), although minor modifications in the arrangement of side- and back-counters will be necessary. The following technical details may be worth mentioning.

1. The counter units

These consist of Plexiglass boxes with outside dimensions 160 × 100 × 18 cm^3 with a wall thickness of 3 cm. Four 5" phototubes 54 AVP are mounted on the upper 100 × 18 cm^2 surface, four further ones on the bottom surface, so as to leave both sides unobstructed. The light collection depends mainly on total reflection; Al-foil loosely wrapped around the boxes gives a further gain. Taking previously measured data on light collection in non-directional water Čerenkov counters, one estimates a light collection between 40 and 50% for the counter described. Because of the absorption in the lead-perchlorate solution, a more realistic value is $\approx$ 30%. The containers are mounted in steel frames which are placed in one iron trough sufficiently large to take the liquid from all counters in case of breakage.

2. Spark chamber units

They will be made according to the recommendations of the "Neutrino Spark Chamber Committee": units made of 3 Al plates, 0.5 mm thick, with 1 cm gaps in between, and an area of again 1.60 × 1.00 m^2. Each unit will be separately sealed and filled with gas (presumably argon + organic vapour). The units can be arranged in any suitable way. It is felt that two units should go in front of each counter.

3. Total and useful weight

One combined unit (= 1 counter + two spark chamber units) contains:

450 kg	$Pb(ClO_4)_2$ - solution
100 kg	Plexiglass
120 kg	Aluminium
670 kg	in total

20 units therefore give 13.4 to total weight, which leads to 10 tons useful weight under the assumption of 75% efficiency.

4. Geometry and photography

The most convenient geometry seems to be an arrangement where two units stand side by side, forming a detector of ≈ 3 m^2 sensitive area. This is very advantageous for avoiding particle losses to the sides. Packing counters and spark chambers closely together (but allowing 2 cm spacing per unit), the whole sandwich gets 2.80 m long.

It is proposed to photograph both sides of the sandwich separately from behind, over mirrors placed under ≈ 45° to the axis. As the high brilliancy of the sparks permits the use of a small aperture (say f/16) the differences in optical path length present no serious problem. There is nothing, in principle, against photographing both sides by one optical system placed on the centre line. However, the increased width of the arrangement would lead to some trouble with the available space.

5. Cost estimate

The total cost of the proposed set-up is as follows:

9000 kg lead-perchlorate solution	at SF 13.50	= SF 121,500.--
20 Plexiglass containers..................	at SF 3000.--	= SF 60,000.--
160 photomultipliers 54 AVP............	at SF 400.--	= SF 64,000.--
40 spark chamber units......................	at SF 800.--	= SF 32,000.--
Electronics for spark chamber trigger (estimated)..		SF 20,000.--
Optical system (estimated)		≈ SF 22,500.--
	Total	≈ SF 320,000.--

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This may be compared with a cost estimate by Gaillard[16] for a total (not effective) 10-ton spark chamber of type A which is triggered by pairs of plastic counters:

32 m^2 of plastic scintillator	SF 100,000.--
64 photomultipliers	SF 20,000.--
Aluminium plates	SF 50,000.--
Plexiglass frames	SF 10,000.--
Electronics for triggering	SF 20,000.--
Optics	SF 20,000.--
Total	SF 220,000.--

6. Remarks on the method of measurement

Although the general method of measurement in the CERN neutrino counter experiment has been outlined previously[3], it may be useful to summarize briefly how the information is obtained and which cross checks can be made.

The neutrino-trigger is a single count (corresponding to $\gtrsim$ 6 cm path length of a relativistic particle) in any of the lead-perchlorate counters which is in anticoincidence with the surrounding NO-counters. This relatively loose signature is feasible because the Čerenkov counters are insensitive to neutron background which is a problem in scintillation counters. This signal

a) triggers an socilloscope on which the pulses from all YES- and NO-counters are displayed;

b) gates a linear adder which adds together the pulses from the lead-perchlorate counters;

c) gates a kicksorter which prints out the time-of-flight of the event[17] (relative to the PS bunch phase);

d) fires all spark chamber units.

a) provides a check for b), and d) is an independent control of a) and b). From the range of a 500 MeV shower[18], one judges that a typical event would involve 2-3 counters and 2 four-gap spark chambers. The probability that the shower is absorbed in one counter is $\lesssim$ 20%. The case that the shower is absorbed in one spark chamber without firing at least one counter is practically excluded.

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Acknowledgements

The author acknowledges stimulating discussions with Professors Bernardini, Preiswerk and Weisskopf, and Drs. Ferrero, Ghani, Knop, Krienen, Reinharz and Salmeron.

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Figure captions

Fig. 1 : Expected resolution of an ideal total absorption lead-perchlorate counter, and of a real one, which has 20% shower losses and 30% light collection. For comparison, the measured error is given for several total absorption Čerenkov counters$^{12-15)}$, sampling counters$^{10,11)}$, and cloud chamber measurements$^{8,9)}$.

Fig. 2 : Schematics of the proposed lead-perchlorate counter spark chamber set-up of effectively 10 tons. A second optical system, identical to the one shown on the left, has to be imagined on the right-hand side.

* * *

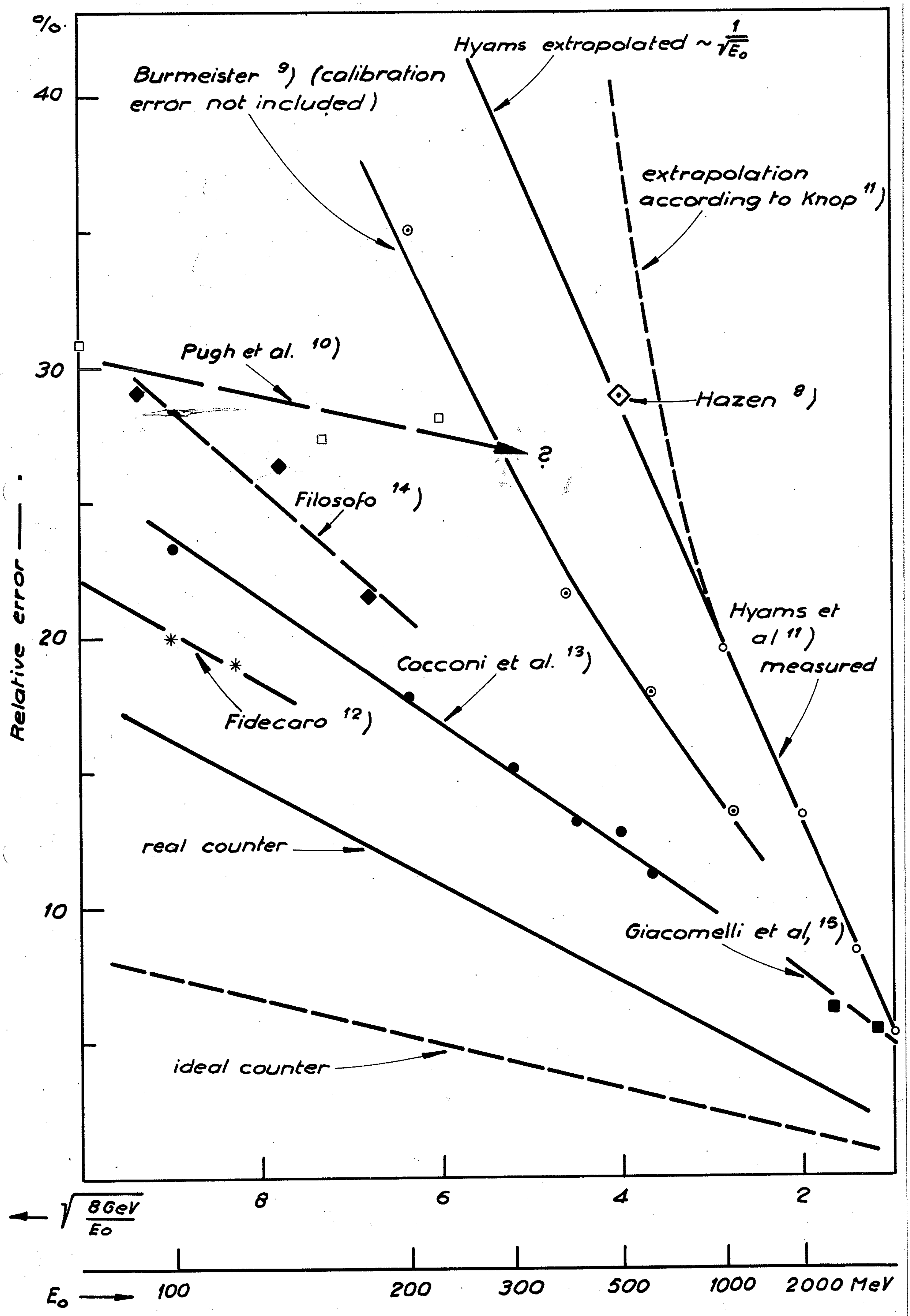
%
40
30
20
10
Relative error
Hyams extrapolated $\sim \frac{1}{\sqrt{E_0}}$
Burmeister 9) (calibration error not included)
extrapolation according to Knop 11)
Pugh et al. 10)
?
Hazen 8)
Filosofo 14)
Hyams et al 11) measured
Cocconi et al. 13)
Fidecaro 12)
real counter
Giacomelli et al, 15)
ideal counter
$\sqrt{\frac{8 GeV}{E_0}}$
8
6
4
2
E_0
100
200
300
500
1000
2000 MeV

Fig. 1

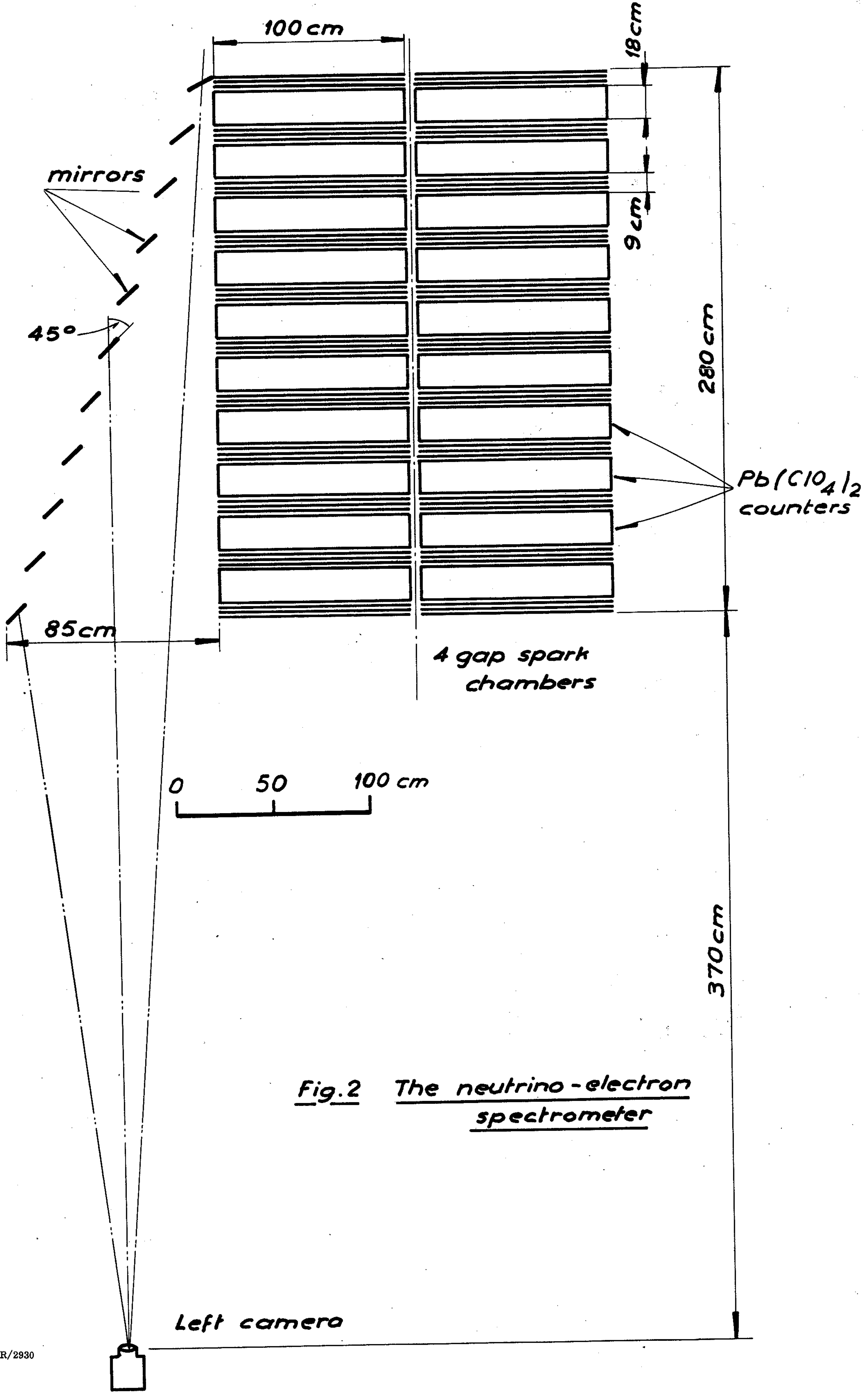

Fig. 2 The neutrino-electron spectrometer

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