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COUNTER ARRANGEMENTS FOR THE CERN NEUTRINO EXPERIMENT

by

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SUMMARY

Some counter arrangements are described which have been in use during the preparatory period of the CERN neutrino experiment. It is shown how the existing counters can be combined into a neutrino detector capable of registering neutrino reactions at a rate of the order of 10^{-1} per ton and day. A 50 ton spark chamber is considered as the final step of the neutrino counter experiment.

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1) Introduction

The theoretical significance of high-energy neutrino experiments has been discussed by many authors[1-5]. It was obvious that these experiments would be difficult with existing accelerators: the neutrino fluxes are low and lead one to expect neutrino reactions to occur at a rate of 1 per ton and day at the best. As a consequence the problem of shielding against background particles becomes difficult.

Both problems, neutrino fluxes as well as shielding, have been treated by Krienen, Salmeron and Steinberger[6] 12.1.60 who arrived at the conclusion that neutrino reactions can be detected by the CERN 750 kg freon bubble chamber, if one uses an internal PS target in straight section 5. The engineering details of the shielding layout for the CERN chamber have been discussed by de Raad and Resegotti[7]. More detailed calculations about the focusing action of the PS fringing field on the pion flux from target 5 were done by Krienen and Salmeron[8]. They showed that the reaction rate expected on the basis of the "conservative" theoretical cross-section estimate[3] is around 0.35 per ton and day for each of the reactions

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

and

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

A critical revision of these calculations by von Dardel[9] revealed that even this rate was too optimistic, and that the true rate presumably is by a factor of 7 lower than that.

Already at a time, when the detailed calculations on neutrino fluxes[8,9] were not yet available, it was felt that a counter set-up could give valuable additional information to the one expected from the search with the CERN heavy liquid bubble chamber[6,7]. A neutrino counter can incorporate 10 to 50 tons without too great difficulty. Consequently, it is the adequate instrument to collect statistics, whereas the bubble chamber is particularly useful for answering qualitative questions like: are there two kinds of neutrinos or not? By now it seems that in the initial stage of the experiment a counter set-up plays a decisive role: with the neutrino fluxes as estimated by von Dardel[9)], a counter of $\gtrapprox$ 50 tons seems to be the only means of detecting them at all[*)].

The present report is meant to give some information on the existing and the planned neutrino counter set-ups. In section 2 some general considerations are made on the type of information which can be obtained with counters. Some specific counter geometries will be described in section 3. The simplest arrangements detect only charged particles produced by neutral ones in a large lead block. The more complicated set-ups include track-showing devices as well. The possibilities and limitations of the neutrino counter experiment are discussed in section 4.

2) The Information obtainable from Counters

The simplest neutrino counter would be a large scintillation or Čerenkov tank. However, the discrmination against background events would then be very difficult, and the identification of specific reactions almost impossible. One has to distinguish the two basic reactions (1) and (2) from each other and from the inelastic processes, where pions are produced in addition to the charged leptons. As the angular distribution at the relevant neutrino energies between 500 MeV and 1 GeV is not very peaked forward, the most natural structure is a sandwich of large but thin counters with appropriate amounts of target material between them. The detector should be surrounded by an anti-

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[*)] It should be stressed that von Dardel in his report[9)] neglects a number of effects which all help to make the neutrino flux bigger. As a result the reduction with respect to the previously expected interaction rate of 0.35 $d^{-1} t^{-1}$ is (according to the present author's estimate) a factor around 3.5 rather than a factor of 7.

coincidence shield which protects it against charged stray particles from the PS and cosmic rays. Care must be taken not to exclude good events by the anticoincidence counters. In the back of the sandwich (and preferably also on the rear parts of the sides) directional Čerenkov counters are used rather than scintillation counters, because they reject only particles entering the sandwich from the outside, but not the ones leaving it. The principle YES-sandwich with ANTI-shield has been adopted in all the set-ups described below.

Because of the low counting rate expected one has to extract the maximum amount of information from each event. This is achieved by using a suitable coincidence signal from the sandwich (= YES) counters (in anticoincidence with the surrounding NO-counters) as a trigger for an oscilloscope on which, with suitable delays between them, the pulses from all the counters are displayed. By pulse-height measurement one gets detailed information about the event in question which will be essential for analysing good events as well as for rejecting false ones. This procedure, by the way, eliminates the electronical inefficiency of the anticoincidence system completely, because even if the anticoincidence circuit failed, the pulse in the NO-counter will be on the scope trace. Accidental coincidences can be rejected as well as soon as the timing is wrong by $\gtrsim$ 10 nsec.

For good events one obtains the following information:

(A) The energy loss $\frac{dE}{dx}$ in every YES-counter from the pulse height. By following dE/dx through several counters, i.e., by measuring $\frac{dE}{dx}(x)$, one can for instance distinguish between electron and muon production.

(B) If the sandwich is sufficiently long the number of YES-counters fired gives the range.

(C) For a sample of neutrino-like events, one can measure the spatial distribution of the starting points. This will be a very severe test, because real neutrino events are the only ones which would be distributed uniformly all over the sandwich.

(D) Of course, the measurements (A) and (B) are unambiguous only if one knows the multiplicity of the event and the angles involved. In order to get this information it is necessary to install a hodoscope, say a series of flat spark chambers, between the counters.

(E) The bunched structure of the radiation permits a determination of the time-of-flight for each event.

Technically the time of arrival of each event (relative to the phase of the RF acceleration voltage of the PS) is printed on each oscilloscope trace. This may be useful for background rejection at a stage of the experiment when effect and background are of comparable magnitude: the neutrino events should show a more pronounced time correlation than the background; moreover, their proper phase can be determined experimentally by using muons coming from the target10).

3) Some Specific Arrangements

3.1) The short sandwich

This is nothing but an enlarged version of a conventional γ-telescope with some additional anticoincidence counters on top and on the sides (Fig. 1). A muon generated in the first lead block will be registered as a triple coincidence between the two scintillation counters Y_1 and Y_2 and the directional Čerenkov counter C, provided it enters the latter with an energy $\gtrsim$ 200 MeV. A less restrictive signature is a double coincidence between either Y_1 and Y_2 or Y_2 and C.

Clearly, this simple set-up is far from being a good neutrino counter. Its detection efficiency for electrons is low, and even for muons its useful mass does not exceed some tons. It has been used in the preliminary runs from February to April, 1961, in order to see which types of background are present rather than to look for neutrinos11). However, an enlarged version of this short sandwich might well be used as an efficient detector of the muon reaction (1) (see section 3.3).

3.2) The counter-controlled cloud chamber

This was conceived as a logical extension of the short sandwich: the counter arrangement would remain basically the same, but the first lead block (the "neutrino converter") would be replaced by a multiplate cloud chamber*). In practice, the dimensions of the chamber and of the associated equipment necessitated a substantial increase of the width of the front anticoincidence counter. Also an effort has been made to increase the solid angle subtended by the counters behind the chamber, because lepton emission close to the forward direction is strongly suppressed by the Pauli principle¹²).

The arrangement as shown in Fig. 2 is a compromise between the postulate of optimum detection efficiency and practical requirements (e.g., free field of view for the cameras). The cloud chamber is triggered by a double coincidence between the semi-directional Čerenkov counter C_B in the back and the scintillation counters Y_B, [designated as $(C_B\ Y_B)^2$], or by the corresponding combinations $(C_L\ Y_L)^2$ and $(C_R\ Y_R)^2$ on the sides - of course in anticoincidence with the scintillation counters F(ront), T(op), R(ight) and L(eft). It has been shown¹³) that the trigger rate under these conditions is at 20 GeV and 2×10^{11} circulating protons/burst of the order of 1 every 10 minutes, most of them actually coming from cosmic rays. It could be further reduced by converting the half directional Cerenkov counters C_B C_L and C_R into directional ones, but there is little point in it, as long as the counters serve only to trigger the chamber.

The cloud chamber contains 9 lead plates of 4 cm thickness, altogether ≈ 2.7 tons. The detection efficiency for muons generated by PS neutrinos is estimated to be $\approx 1/3$ which makes the counter controlled cloud chamber a muon detector with an effective weight around 1 ton. (The detection probability for electrons is $\lesssim 8\%$.) As far as the expected reaction rate is concerned the chamber is therefore comparable to the bubble chambers engaged in the neutrino search. Advantages are: the additional information supplied by the counters (see section 2) and ease of scanning. The disadvantage: less information about the kinematics. It would be desirable to get rid of the detection threshold of the Cerenkov counters (≈ 170 MeV) and to trigger with scintillation counters only. However, this is not possible at the present background level[11,13].

3.3) The broad sandwich

This is a pure counter set-up incorporating 50 tons of lead with an over-all detection efficiency for neutrino-produced muons $\gtrapprox$ 30%. It is made out of the components already in use for triggering the cloud chamber. The following changes in geometry are suggested: the lead wall behind the FRONT-counter (Pb-dimensions $300 \times 240 \times 60$ cm^3) is covered with scintillation counters. The two big Čerenkov counters C_L and C_R ($240 \times 120 \times 80$ cm^3 each) are made directional counters, using the phototubes from C_B. They are placed ≈ 1 m behind the scintillation wall (Fig. 3). Again a double coincidence $(YC)^2$ will be demanded.

This set-up will register neutrino reactions at a rate of the order one per day even with the (pessimistic) neutrino fluxes as given by von Dardel[9]. The background trigger rate, as extrapolated from the data obtained with the set-up of Fig. 2, will be less than an order of magnitude higher. At a PS energy of 19 GeV it is practically only due to cosmic rays. If one uses all the information obtainable from the counters: pulse height, pulse-height correlation and time-of-flight (see section 2), there seems to be a fair probability of detecting neutrino reactions unambiguously. But even if this should turn out to be impossible, at least an upper limit can be set on the rate of muon-producing neutrino reactions.

3.4) The counter-controlled spark chamber

In the course of the neutrino experiment, one wishes not only to detect high-energy neutrino induced interactions, but rather to measure cross-sections of specific reactions as a function of momentum transfer. It is therefore essential that the information as derived from the counters is augmented by data from a hodoscope, suitably incorporated into the counter sandwich. (In fact, the use of the cloud chamber into the counter set-up was already a step in this direction.) In the early discussions about the neutrino counter set-up, several kinds of hodoscopes were under consideration: pulsed Geiger-Muller-counters, Conversi flash-tubes and spark chambers. The recent development of large and seemingly reliable spark chambers speaks very much in favour of the latter.

Only for orientation purposes in Fig. 4 a somewhat obsolete drawing of such a set-up is given. The spark chambers have two gaps only, and some target material is piled up in front of them. Recent developments in Brookhaven(14) indicate that one should make up the single chambers of 5 to 10 gaps, incorporating all the target material into the chamber plates. Also the half-directional Čerenkov counters indicated in Fig. 4 should better be made fully directional. Yet the general layout (including the photographing by mirrors) is likely to be adopted in the final arrangement.

As was shown in the background runs(11) one can trigger the spark chamber with a single count (with $dE/dx \geqq 15$ MeV) in any of the scintillation tanks, which is in anticoincidence with all the NO-counters. The detection efficiency of the counter triggered spark chamber can therefore be made close to unity for both muons and electrons. As an effective weight of 10 tons can be realized without too great difficulty, and even 50 tons seems to be manageable, the counter triggered spark chamber at present appears to be the best suited apparatus for the neutrino experiment. A very attractive modification deserves special mentioning: a spark chamber which by itself weighs $\approx$ 10 tons can be used in conjunction with magnetized iron plates. The plates should have a thickness of $\gtrsim$ 20 cm in order to overcompensate the multiple scattering by the magnetic deflection. Thus a muon spectrograph of $\approx$ 50 tons useful weight can be realized which would permit a much better study of the muon reaction (1) than the other set-ups described so far*). Design studies are underway.

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*) An arrangement of this type has been proposed by Bernardini more than 1 year ago. The proposal to use thick Fe plates separated from the hodoscope is due to Wolfendale (private communication), who incidentally recommended flash tubes for the hodoscope.

4) Conclusions

It is obvious that the future progress of the neutrino experiment has to go in two directions:

a) higher neutrino fluxes;

b) bigger and better detectors.

As far as the fluxes are concerned, there are two stages of development:

α) improving the fluxes from target 5 by changing it into a long section[15] and/or by using "kicker" magnets in order to accept smaller production angles[16]. This "conventional" improvement could be done by September-October and would bring the total interaction rate approximately back to the old value[8] of ≈ 0.3 per elastic channel day and ton.

β) The use of an extracted proton beam from the PS together with a directive device, such as van der Meer's horn[17]. This could enhance the total interaction rate to several per day and ton. It is being persued by van der Meer, de Raad and several other members of Ramm's group[18], but its realization would take approximately one year.

In view of the theoretical significance of high-energy neutrino reactions[1-5] it seems not advisable to wait as long as that. A big and efficient detector, like a counter-spark chamber set-up can well be used with an internal target. It is felt that a 10 ton set-up can be built until October - November, provided one uses the already existing counters[*]. As a preparatory step one should attempt to detect neutrino-produced muons by counters alone. As outlined in section 3.3) this seems to be not impossible even with the present low neutrino fluxes: one expects ≈ 1.5 events per day and a background which is not very much larger. Moreover, the distinction

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[*] A 50 ton arrangement would not be ready before March 1962.

is not too difficult, because at 19 GeV PS energy the background comes essentially from cosmic rays[11, 13].

The run can take place in July, as originally scheduled. The procedure would be as follows:

A) Measurement of the cosmic-ray background rate. (If for any unforeseen reason the rate is > 10 d^{-1}, the run can be cancelled.)

B) Calibration of the time-of-flight with muons coming from target 5 through the μ channel. (1 shift, PS energy 28 GeV, no magnetic field in Lagarrigue's chamber!)

C) Main run ($\gtrsim$ 20 shifts, 19 GeV, 1 pulse every 2 seconds).

There is hope to identify neutrino reactions during this run. If not, an upper limit of the order of 10^{-38} cm^2 can be placed on the cross-section. In view of the uncertainties in the theoretical cross-section even this would be a significant result. Moreover, the experience from this run is considered essential for the proper design of the multi-ton devices foreseen for the future.

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CAPTIONS OF FIGURES

Fig. 1 : The short sandwich used in the background runs February to April 1961. Variable amounts of lead (typically ≈ 10 tons), with a muon detection efficiency between 10 and 25%, depending on trigger signature.

Fig. 2 : The counter-controlled cloud chamber. 2.7 to Pb in the chamber, muon detection efficiency ≈ 30%. The lead wall in front of the chamber can give additional events. [Up to now it was only 80 cm high.] The Cerenkov counter indicated with the broken lines is not yet in operation.

Fig. 3 : The broad sandwich. 50 to Pb with a muon detection efficiency of ≈ 1/3.

Fig. 4 : The long sandwich (schematical). Alternating layers of target material, flat spark chambers and scintillation counters. An effective mass of ≈ 50 tons can be reached for muons, ≈ 10 tons for electrons.

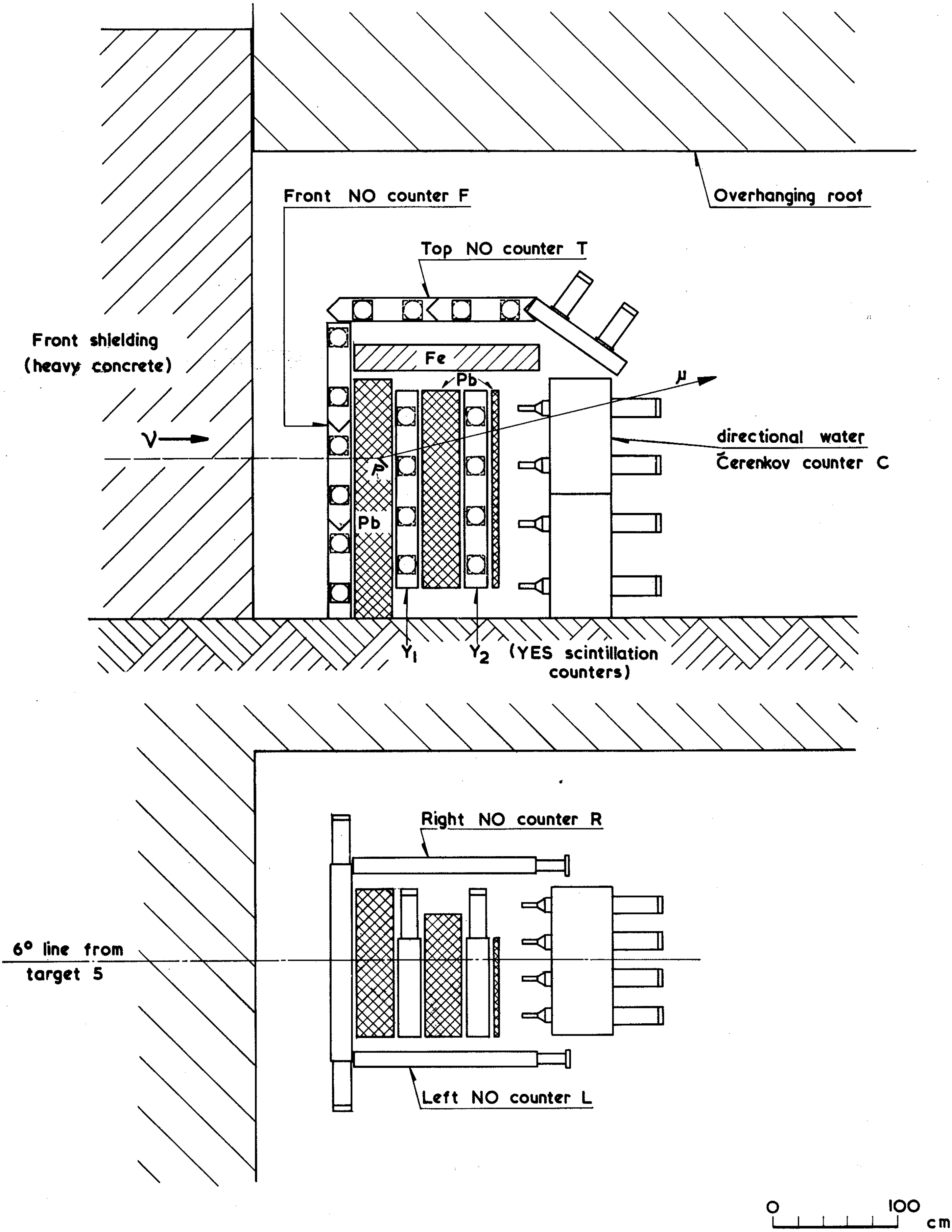

FIG I THE SHORT SANDWICH

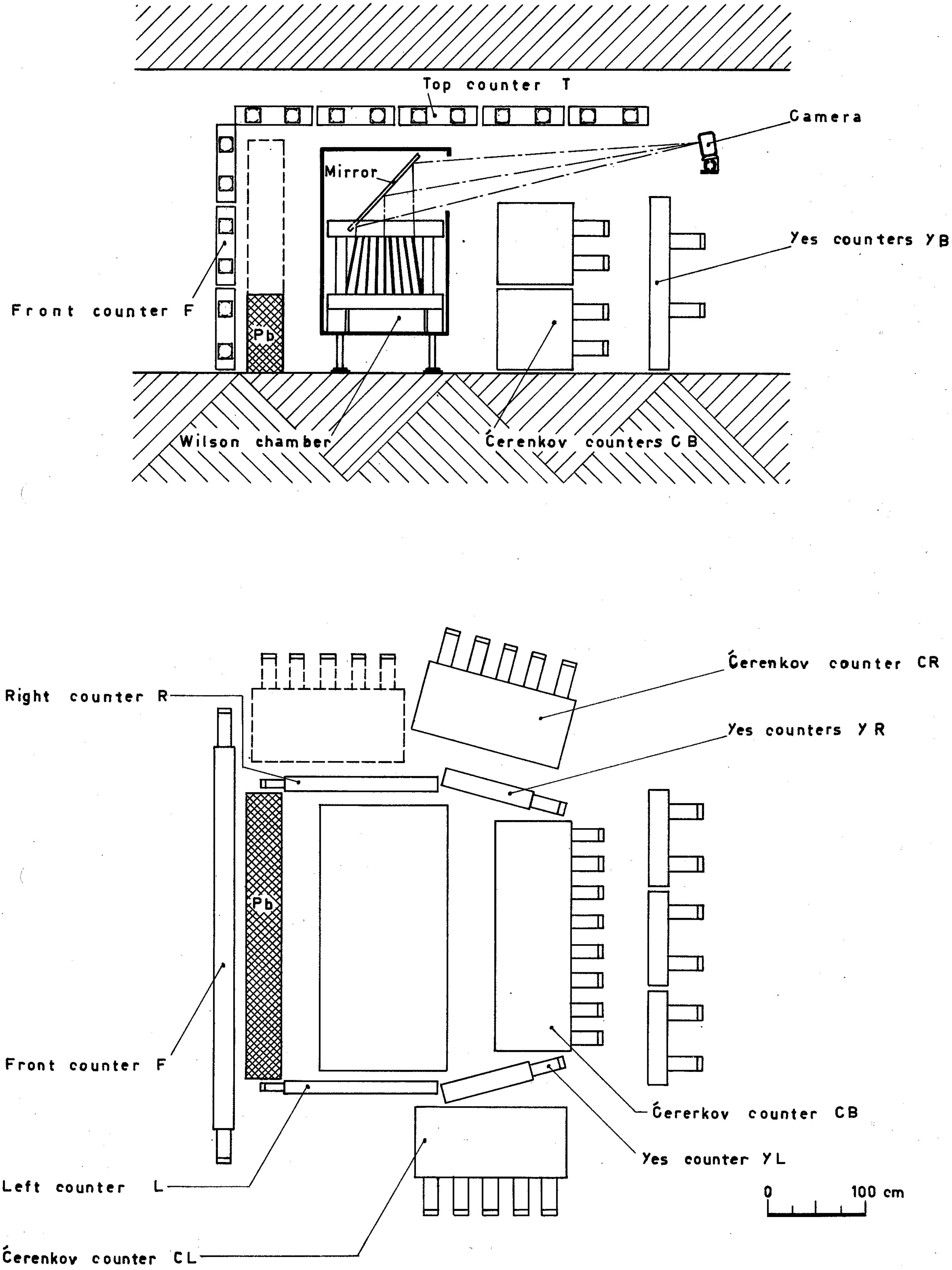

FIG.2 THE COUNTER CONTROLLED WILSON CHAMBER

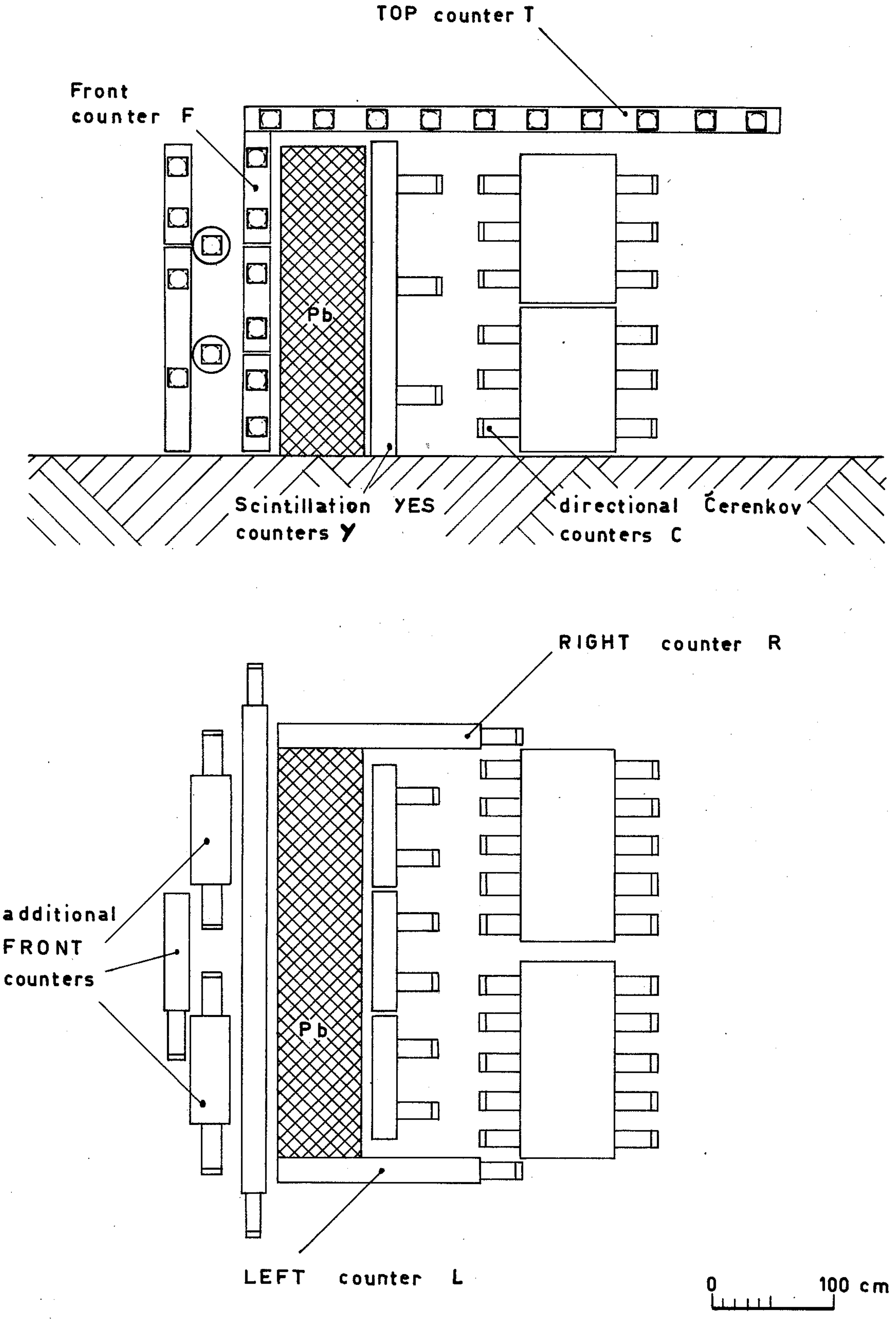

FIG. 3 THE BROAD SANDWICH

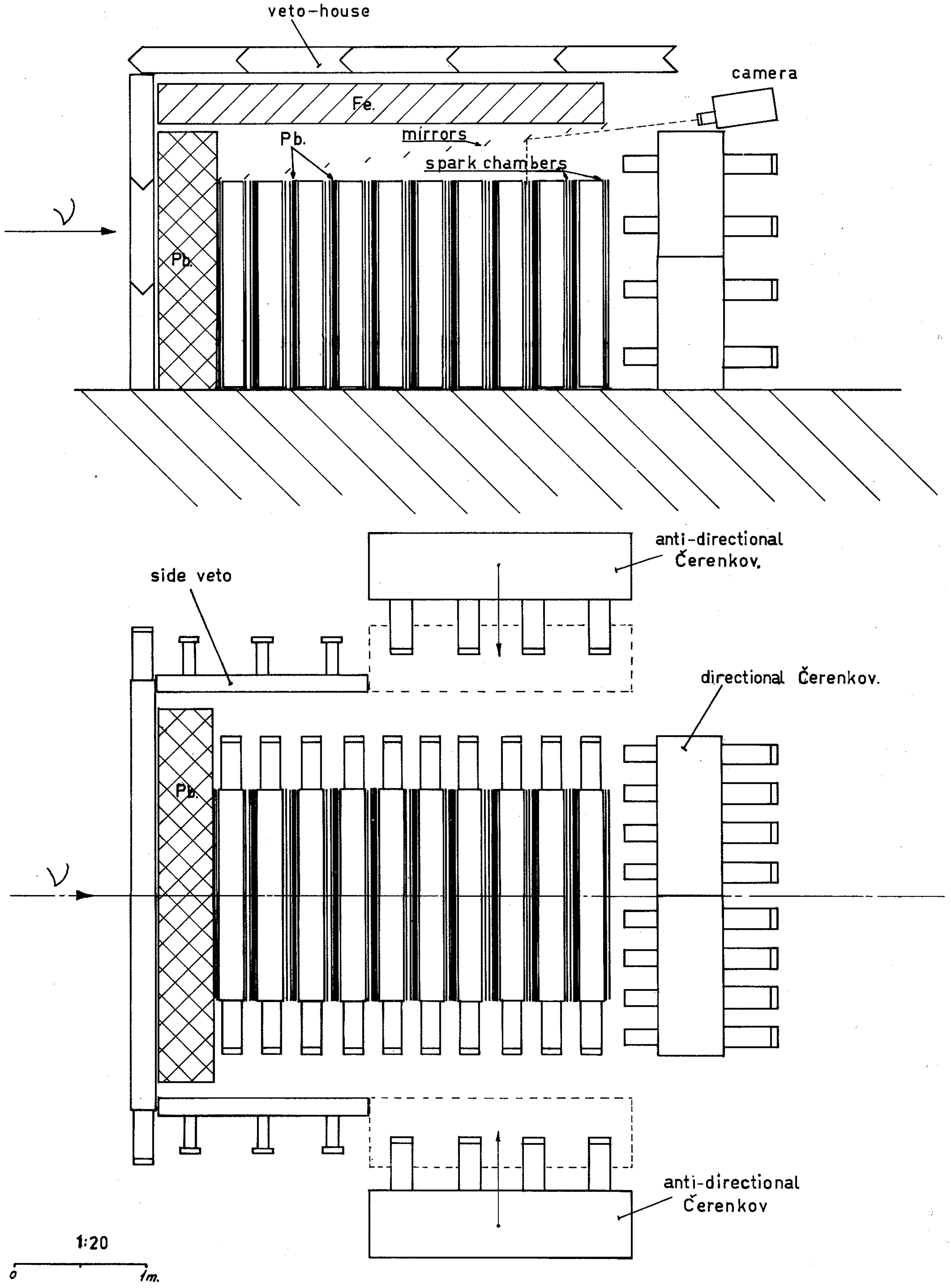

FIG. 4 THE LONG SANDWICH

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