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INTERSECTING STORAGE RINGS COMMITTEE

PROPOSAL

SEARCH FOR FRACTIONALLY CHARGED PARTICLES IN I4

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INTRODUCTION

The quark search has now proceeded for some six to seven years without the question being resolved either way. It is hoped that the intersecting storage rings will provide valuable additional information in this regard.

Previous machine experiments serve to place a lower limit on the quark mass of ~ 5 GeV, down to a level of about 10^{-9} mb [1]. The ISR now raises this mass limit for possible quark production to $\sim$ 25 GeV.

The only experiments exploring this energy region up till now have been performed with cosmic rays. No conclusive evidence for quarks has been reported either by experiments with emulsion stacks or by experiments employing counter telescopes. In actual fact the latter have reached an upper limit for the flux of 10^{-10} cm^{-2} sec^{-1} sr^{-1}. This flux corresponds roughly to a production cross-section of - 10^{-4} mb (cf section on attainable limits).

The ISR, therefore, might have a good chance of observing quarks if :

a) the experiment is sensitive to cross-sections less than 10^{-4} mb,

or b) for some reason (i.e. bad detection efficiency for emulsions and perhaps accompanying particles for counter telescopes) quarks have been missed or obscured in the cosmic ray experiments.

Not all the results have been negative however ; the Sydney candidates [2] were seen visually in Wilson cloud chambers, in the cores of air showers, and have since been debated from many quarters. If indeed they are quarks, their charge would be non-integral.

The two "quark-like" events caused by random cosmic rays passing through the Argonne Michigan heavy liquid bubble chamber [3] have likewise been debated from both sides. Again the question remains unresolved (although it is interesting to note that neither of these two events could be classified as "ordinary" bubble chamber photographs because of the very high energy cosmic ray particles accompanying the quark candidates). A flux of 10^{-8} cm^{-2} sec^{-1} sr^{-1} is quoted for these events which occurred under 1200 gm/cm^2 of shielding. If these events are to be believed, the mass would be about 6 - 8 GeV and the charge would be non-integral.

Another experiment yielding candidates is the underground telescope (70 m.w.e.) experiment carried on at Torino [4]. In this, ionization, delay from shower front and mean free path are simultaneously monitored and a flux of 10^{-8} cm^{-2} sec^{-1} sr^{-1} weakly ionizing, delayed particles is reported. If this result is to be believed, then quarks are heavy, with a non-integtal charge and a mean free path about three times that of the nucleon for strong interactions.

The current work being carried on at Stanford University [5] with niobium spheres suspended by a magnetic levitometer has also suggested the presence of fractional charge on one sphere (mass 7×10^{-5} gm).

Finally, we note evidence for high transverse momenta in extensive air shower cores [6] (i.e. ~ 10 GeV/c); such a transverse momentum allows fast heavy particles to be emitted in the laboratory system at wide angles. A 10 GeV particle with a transverse momentum of 10 GeV/c will still have a $\beta = 0.8$ at 45° in the laboratory system.

Bearing these possible properties of quarks in mind, we propose an intermediate solid angle experiment sensitive to fractionally charged particles with $\beta \gtrsim 0.35$ $\beta \gtrsim 0.8$ (for charges 1/3 e 2/3 e respectively) to be performed in I4 in conjunction with the split field magnet facility, before the arrival of the magnet.

Having a solid angle of 1 steradian, the experiment will have good accomodation for accompanying particles and will have material capable of producing unwanted particles kept to a minimum. It will be sensitive to quark production betweem laboratory angles of 5° and 50°.

In addition to this, we describe a similar downstream detector to search for any quarks that are produced at very small forward angles.

The techniques of identifying fractionally charged objects by their anomolously low ionization in a scintillation telescope are well known and are employed in our set-up. Equally well known is the fact that the multiplicity of produced relativistic particles in the ISR energy region could well be as high as 16 (though a mean value of 10 charged particles is suggested by the latest cosmic ray results)[7]. In order, therefore, to avoid having a fractionally charged object always accompanied in the telescope by a fast meson, a system of independent telescopes is required.

We propose a system of 10 independent telescopes covering a total solid angle, from the diamond center, of 1 Steradian. In addition, we would use the proportional chambers of the SFM facility to yield precise information on the position of each candidate in the telescope, so that the variation in the pulse height as a function of position in the scintillators could be taken into account. Furthermore the information from the chambers is needed to make sure that candidates come from the diamond.

There is another incentive for using the proportional chambers ; they could be adapted to yield information on the ionization of passing particles as well as on their position. This is discussed more fully in the section describing the experimental arrangement.

ATTAINABLE LIMITS

What is the smallest cross-section for quark production that one can hope to see with this experiment ?

For an interaction rate of 10^5/sec in the diamond, and a rejection of 10^{-9} (cf section on background), one is left with a lowest acceptable rate of $\approx$ 1 quark every 10^4 seconds. For a luminosity of 10^{30} $cm^{-2} sec^{-1}$ and a geometry of 4π steradians, this corresponds to a cross section of 10^{-34} cm^2 or 10^{-7} mb.

If we now consider our solid angle of 1 steradian, this figure becomes $\sigma_{min} \gtrsim 10^{-6}$ mb.

It is interesting to compare this figure with the fluxes of 10^{-8} cm^{-2} $sec^{-1} sr^{-1}$ quoted by cosmic ray workers. If we assume that quarks can be produced with a constant cross-section σ for any strong interaction of energy $\geqslant 10^3$ GeV, we can use the cosmic ray energy spectrum to obtain an equivalent cross-section.

The primary differential energy spectrum is well approximated by

$$J_1(E)dE = 2.05\ E^{-2.6}\ dE \quad \text{for} \quad 10^3 \leqslant E(\text{GeV}) \leqslant 10^6$$
$$J_2(E)dE = 2680\ E^{-3.1}\ dE \quad \text{for} \quad E(\text{GeV}) > 10^6$$
$$cm^{-2} sec^{-1} sr^{-1}$$

Approximating the number of collisions with energy greater than 10^3 GeV in a shower of total energy E, by $\frac{E}{10^3}$; the total flux of interactions capable of quark production is :

$$\int_{10^3}^{10^6} J_1(E) \cdot \frac{E}{10^3}\, dE + \int_{10^6}^{\infty} J_2(E) \cdot \frac{E}{10^3}\, dE = 5.4 \times 10^{-5}\ cm^{-2} sec^{-1} sr^{-1}\ .$$

Assuming the probability of quark production in each interaction to be $\frac{\sigma(mb)}{40(mb)}$ we obtain the flux of quarks as $5.4 \times 10^{-5} \cdot \frac{\sigma}{40}$.

Equating this to 10^{-8} gives $\sigma = 8 \times 10^{-3} \sim 10^{-2}$ mb. This very rough figure agrees with a more extensive calculation using diffusion equations [8].

Thus provided the cross-section is not too energy dependent , this ISR search should have a good chance of seeing some produced quarks if 10^{-8} is to be believed as the cosmic ray flux.

Finally, it should be noted that the masses of 6-8 GeV suggested by some experiments place the quark just out of the reach of the Serpukhov accelerator but easily within the reach of the ISR facility.

EXPERIMENTAL SET-UP

A schematic of our proposed layout is shown in fig. 1, 2, 3. It consists of a system of 10 independent scintillator telescopes, all above the pipes, with Charpak chambers to yield precise position measurements. One wire plane of each chamber is shown in the figures. The layout was designed around the sizes of the already existing chambers of the SFM group.

Each telescope consists of 9 scintillator planes, three for triggering and six for pulse-height analysis. A trigger will result when all three trigger counters of any one telescope yield pulse-heights out of the noise, but less than minimum ionizing ; at this time, the pulse-heights in each of the six pulse-height counters in the same telescope, are digitized and read out. It is important to note that the solid angle subtended by the trigger system is within that of the pulse-height counters, so that edge effects in the scintillators faking a low-ionizing event are eliminated. In addition, the trigger counters themselves are aligned in such a way that edge effects in them giving rise to too many triggers are minimized.

We anticipate, especially when the ISR reaches full intensity, that 3 trigger counters will not be sufficient to cut the trigger rate down to the level of approximately one per second. Therefore, two of the pulse-height counters will also be available for use in the trigger as well.

Figure 4 shows a proposed scheme for the electronics. There is one trigger unit per telescope and one digitizing unit per plane. A candidate opens the gate which allows the appropriate 6 PM signals (which have been delayed long enough for the trigger to occur) to be digitized. As described earlier, a candidate is defined by a three fold coincidence among the trigger counters for any one telescope, with window discriminators rejecting most minimum ionizing triggers. In addition, we require a 3-fold coincidence along the other pipe-signals S1, S2, S3 (not shown in the layout diagram) in order to exclude unwanted beam-gas triggers. For each candidate, pattern units record which telescope gave the trigger, as well as which other telescopes had (minimum ionizing) coincidences at the same time.

All the scintillators of a given plane are linearly wired into the same ADC, through linear gates. The gating is arranged such that in each scintillator plane only the pulse from the PM in the trigger telescope is digitized.

The pulses in the appropriate telescope are displayed on an oscilloscope, together with the gate signals, and are photographed for each candidate. In addition, the pulses from the three trigger counters are also displayed.

Finally, the proportional chambers are read out for each candidate. All the information for each candidate, excepting the visual record, is directed to the EMR 6130 computer.

As mentioned earlier, position information from the proportional chambers will allow for precise corrections for light attenuation in the scintillators. If the chambers are run with the normal gas (A, CO_2, n-Pentane) with 300 ns gate widths, considering their gap size, approximately 50 ions are collected for a nimimum ionizing particle. Thus, in such a configuration, a mean number of about 5 would be expected for a charge 1/3 object. The probability of such a quark being seen in all six gaps is therefore approximately 95 %.

In addition, some runs could be taken with a smaller gate width on some of the gaps of the position measuring chambers, or on the gaps of a separate chamber altogether. For instance, with a 50 ns gate width, one would expect one ion for a charge 1/3 object and thus a poor quark detection efficiency. This would be an additional signature for a fractional charge. If reliable, this feature could certainly add to our rejection power.

Thus for each candidate, we have six samples of its ionization, where edge effects have been eliminated due to the arrangement of the trigger counters. The visual information will be invaluable in rejecting possible out-of-time pulses in some of the scintillators. We will also know the multiplicity (in our telescopes) associated with each candidate ; such information will be of obvious value in verifying possible anomalous behaviour.

BACKGROUND

There are two categories of background which can be troublesome. Firstly the background of accompanying particles which cause an event to be rejected even though there may be a quark present. Secondly there is a possibility of a non-quark simulting a quark response.

a) There is firstly the problem of accompanying mesons. Appealing to cosmic ray data again [(9)], we find an expected charges multiplicity for this energy $\lesssim 10$. Latest experiments carried out with hydrogen targets and ionization calorimeters at mountain altitudes [(7)] suggest a multiplicity increasing with the logarithm of the available energy, so a figure of 10 is reasonable for 1600 GeV.

Again, resorting to measured anisotropies of cosmic ray interactions [10], we can expect roughly one quarter of these particles (mainly π's) to be produced within an angle of 24°, and the other quarter to be spread out over the remaining angular region of $24° \leqslant \theta \leqslant 90°$. Therefore at 1.5 metre downstream, the position of our trigger plane T_3, one quarter of the π's (say 4 for an upper limit multiplicity of 16) will be distributed over a circle of radius 66 cm. This circle is drawn onto fig. 3 and as can be seen, the accomodation for accompanying particles is good.

Knock-on electrons may also obscure a real event. For a relativistic quark (charge 1/3 e) incident upon a stack of nine scintillators of thickness 1 cm, we calculate the chance of rejecting the event as being roughly 5 - 6 %. For charge 2/3 e particles the effect is obviously worse (dependent upon Z^2) but we feel that the experiment would be workable even if this figure were as high as 30 %.

Because of these effects, and others such as nuclear interactions, and electromagnetic effects, we aim to use scintillators 1 cm thick, of the material with the best light output and absorption characteristics (probably a NUPLEX plastic).

b) The problem of a normal track simulating a 2/3 e or 1/3 e particle must now be considered. We have measured the pulse height distribution for minimum ionizing cosmic rays (μ mesons) using a 1 cm thick scintillator. The scintillator and phototube were of the type intended for the final experiment. We obtained a full width at half maximum of 36 %. In addition, particles of charge 2/3 e and 1/3 e have been simulated using filters in front of the photocathode of the measuring tube.

From these measurements we can state that a telescope of six <u>independent</u> such scintillators will give a rejection of 0.37×10^{-10}, with an efficiency of >50 % for detecting particles of charge 2/3 e. However, when assembled and running under experimental conditions, there could be correlations between the scintillators which would reduce our rejection capability.

We are incorporating the following features to make the distributions even narrower :

(i) accurate position measurements from the chambers, so that corrections for absorption and edge effects can be made,

(ii) good coupling (from 1:1 to 1.5:1) of the scintillators to the photomultipliers via light guides,

(iii) accurate and frequent monitoring of the gain and stability of the electronics chain via light emitting diodes.

With these incorporations, as well as with the information provided by the three additional ionization samples in the trigger counters, we are confident of a figure of 10^{-9} or better for rejection (with > 50 % detection efficiency for charge 2/3 e). Moreover, we may also be able to use the ionization information from the Charpak chambers which will make the rejection even better. The final value, of course, needs to be measured under beam conditions and this will be done as one of our preliminary measurements.

There are, in addition, other ways to simulate a fractionally charged response. If the primary be a shower of γ rays, for instance, energy can be dumped in the scintillator via photoelectric effect, compton collisions and pair production. We calculate that the probability of a photon depositing an electron of energy 100 KeV $\leq$ E $\leq$ 1 MeV (in the range to be expected from a 2/3 e quark) is in most cases negligible. However, it can rise as high as 5 % for an incident γ ray of energy 300 KeV - 1 MeV having a compton collision ; pair production gives a corresponding probability of ~ 0.5 % (1 cm of scintillator is only $\sim 1/40$ of a conversion length) and the photoelectric effect gives a figure of $\sim$ 0.1 %.

Thus the chance of having a quark simulation from a γ ray is about $(0.05)^9$ provided there is a γ ray in this energy region and provided it does not scatter out of the telescope.

There are still more effects capable of simulating a fractionally charged particle. These are listed in the following table together with the safeguards offered by the experimental arrangement :

EFFECT	SAFEGUARD
Cerenkov radiation from light guides	No signals in chambers Anti Counters
Attenuation in scintillators	Attenuation only 17 $\pm$ 3% per meter accurate positioning from chambers
Partially digitized out of time signals	Oscilloscope display
Interactions of neutrons in telescope	Thin scintillators Each scintillator $\sim$ 1/80 mean free path
Upwards fluctuations of noise	No signal in chambers No coincidence from S_1 S_2 S_3

DOWNSTREAM DETECTOR

Some theoretical considerations (11) are in favour of a diffraction like process for quark production. Under these circumstances, the produced quarks will be focussed into the very forward cone. To take care of this eventuality, we propose a downstream telescope, located 8.5 m from the center of the diamond, as seen in fig. 5. Four telescopes similar to the telescopes of the central region will cover vertically the angular range from 7.1 mrad to 100 mrad. Particles produced at small angles have to traverse a considerable amount of material because of the 2.5 mm thick wall of the present vacuum pipe. A particle emitted at 20 mrad has to traverse 12.5 cm of steel corresponding to 0.7 interaction lengths. These figures became more favorable for bigger angles.

CONCLUSIONS

The majority of electronics required for this effort, as well as photomultipliers and bases, will be available when the last run of the Münich-CERN PS experiment is over. Major items which we would need to obtain are the electronics associated with performing the digitizations as well as about 20 m^2 of scintillation material.

We would also need some PS test beam time to experimentally measure the statistical properties of our overall system. We plan to have one of our ten telescopes operational ten weeks from the date of acceptance.

We feel that what we have proposed is a reasonable low-cost first generation quark search that would fit most naturally into the test and survey activities of the S.F.M. group.

COLLABORATION

The S.F.M. detector group would supply four proportional chambers with a total of 5000 wires, the corresponding electronics, CAMAC interfaces and computer.

The group would actively collaborate in the experiment, subject to the priority given to their principal activity.

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Figure Captions.

Fig. 1. Side view of the layout.
T1, T2, T3 denote trigger counters.
PH1, PH2, PH3, PH4, PH5, PH6 denote pulseheight counters.
C1, C2 denote Charpak chambers.

Fig. 2. Top view of the layout.

Fig. 3. View of trigger plane T3, the largest scintillator plane, as seen from the diamond; on the average, two particles per interaction are expected within the arc shown (see text).

Fig. 4. Electronics layout.
T2-1 is the signal from the second trigger counter in the first telescope.
PM 2-1 is the signal from the second pulse height counter in the first telescope.
S1, S2, S3 are signals from a small telescope along the other pipe.

Fig. 5. Downstream Layout.

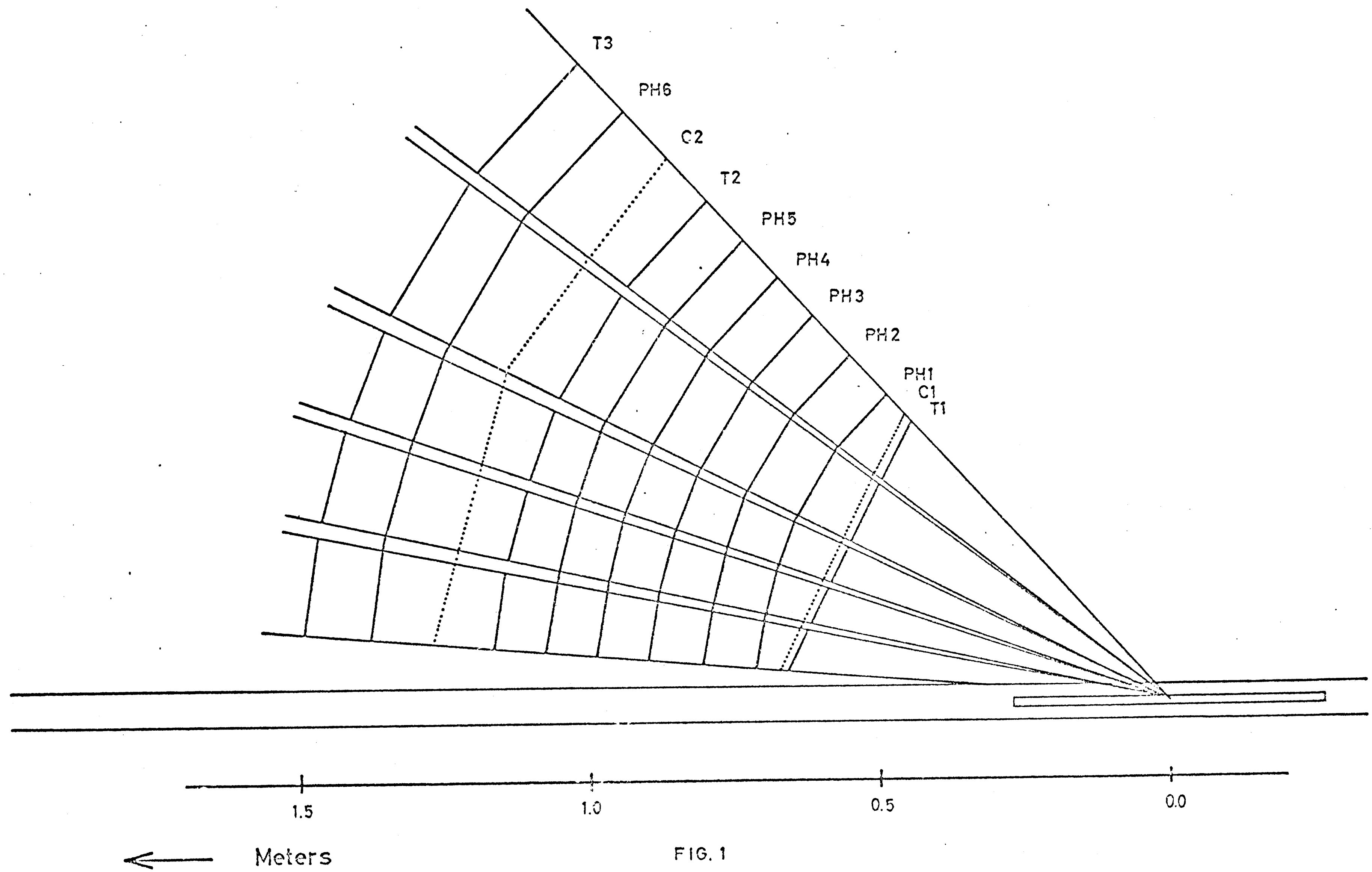


FIG. 1

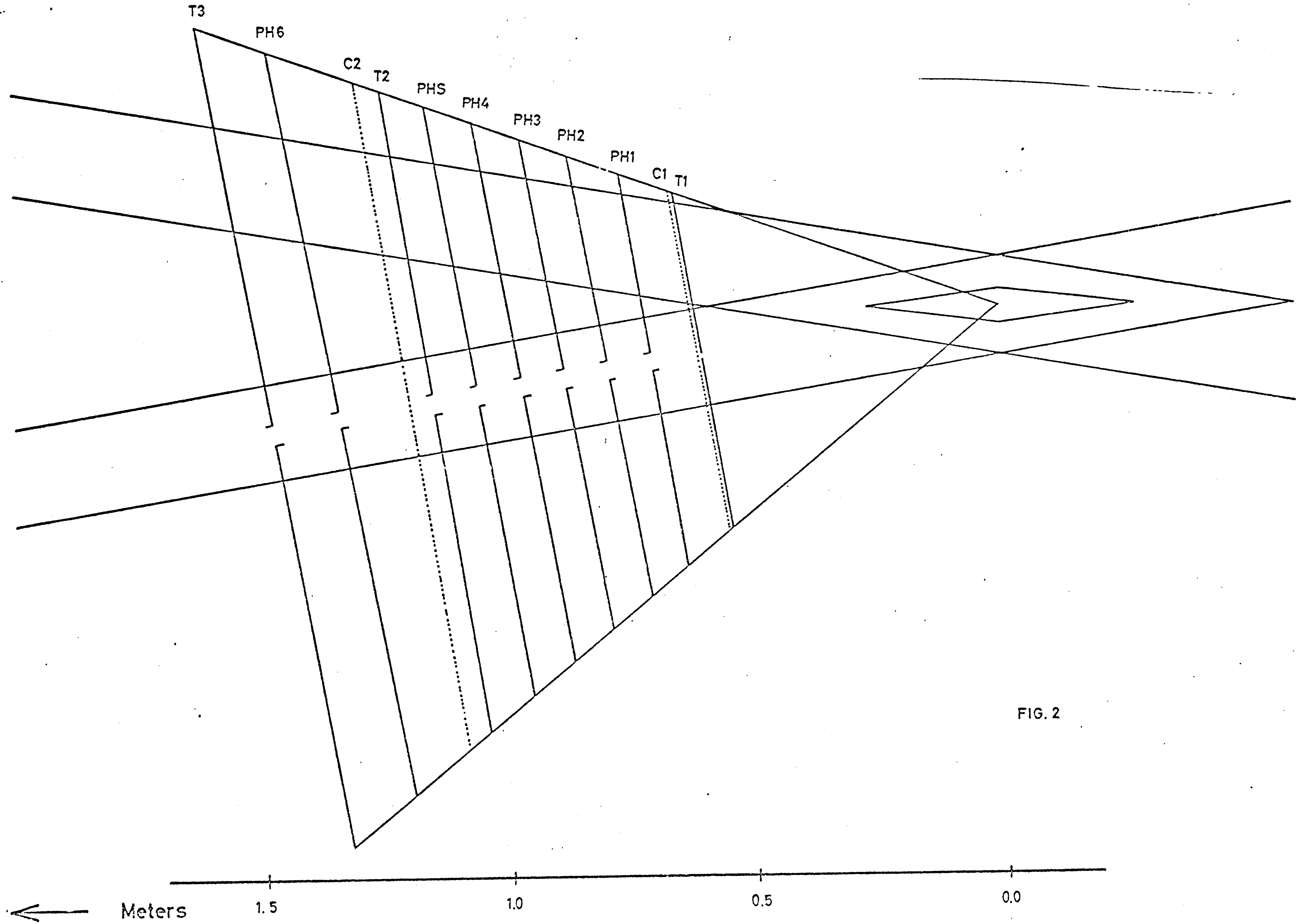


FIG. 2

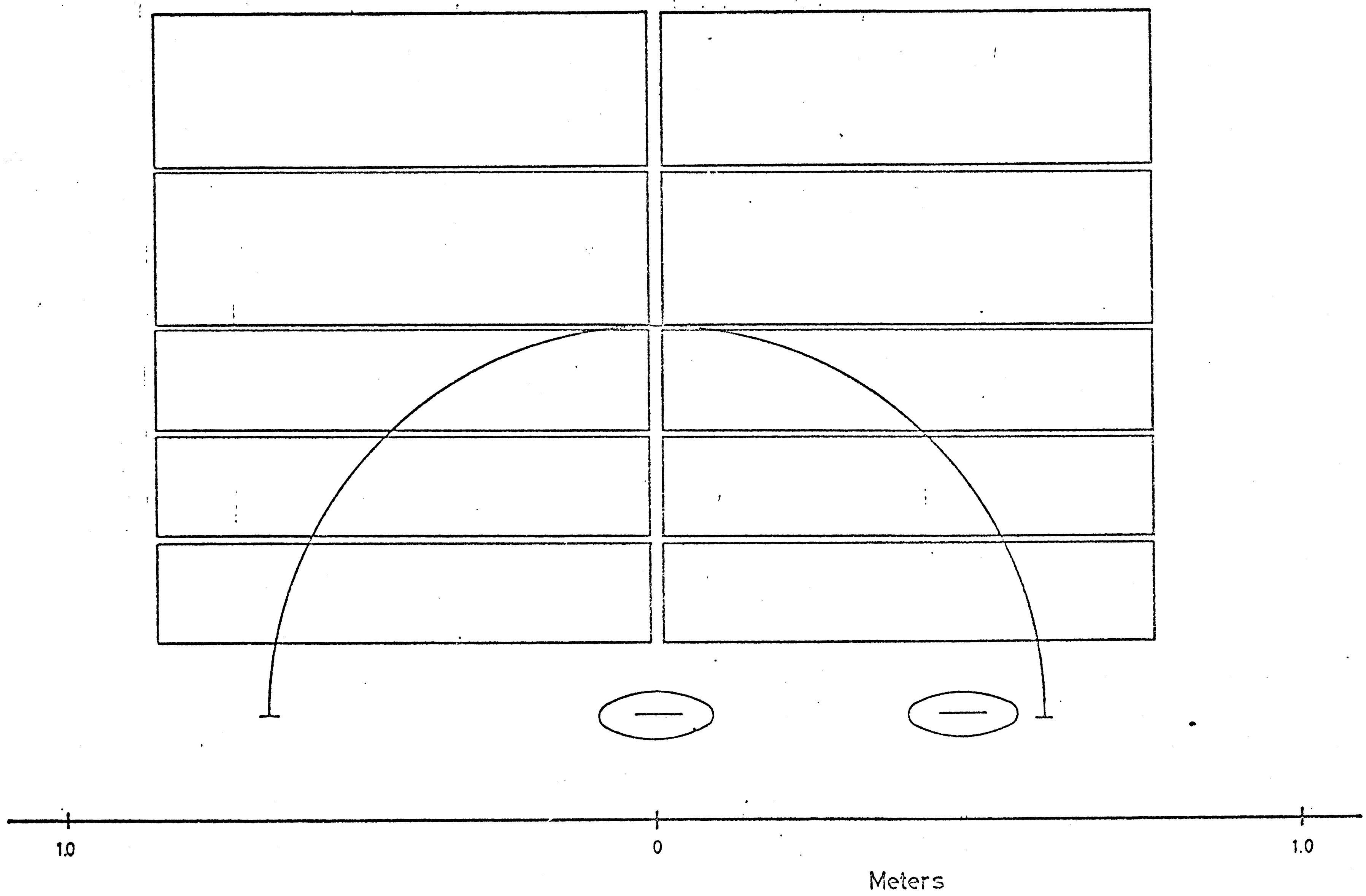
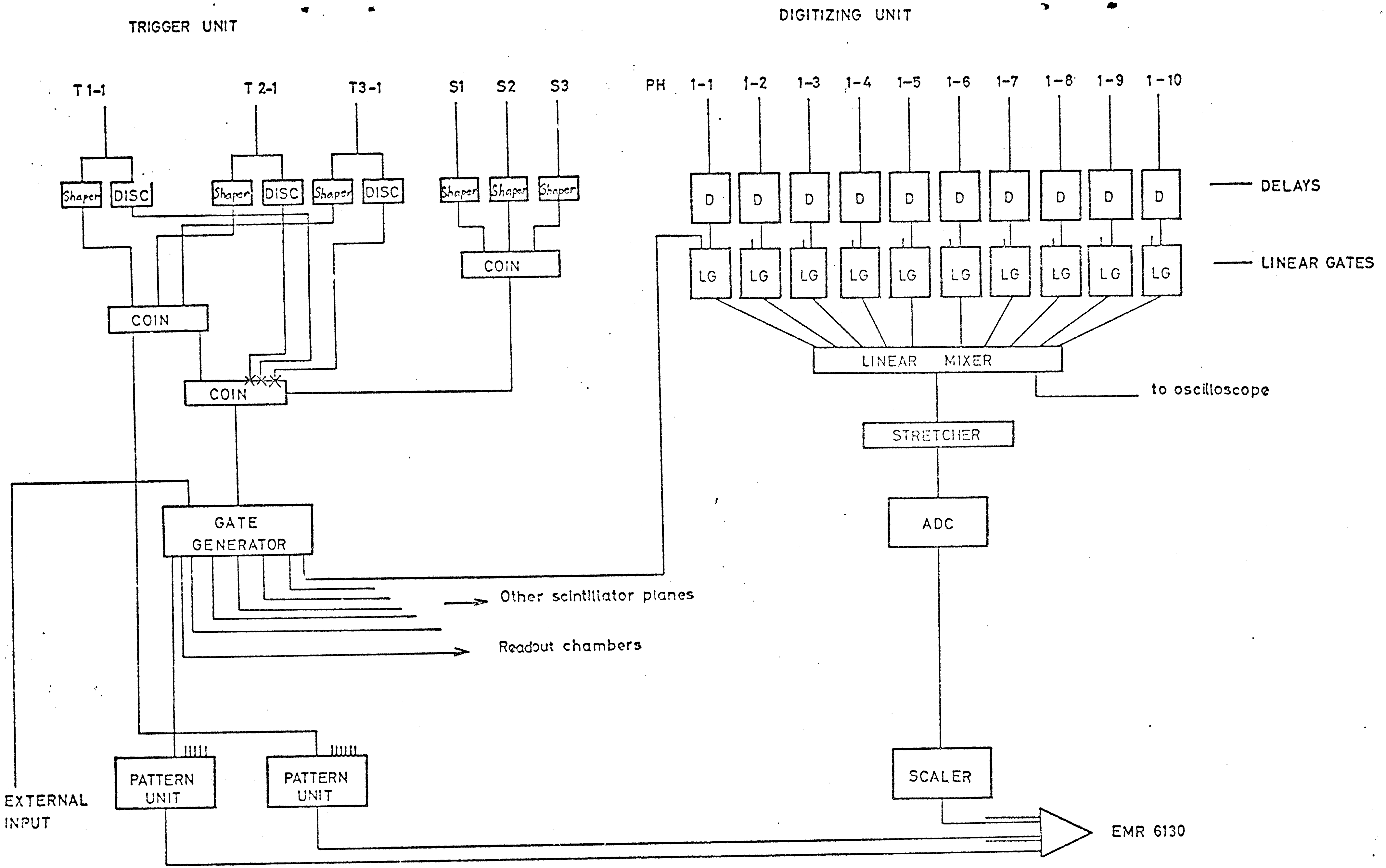


FIG. 3



TRIGGER UNIT
DIGITIZING UNIT
T 1-1
T 2-1
T3-1
S1
S2
S3
PH
1-1
1-2
1-3
1-4
1-5
1-6
1-7
1-8
1-9
1-10
Shaper
DISC
COIN
D
LG
DELAYS
LINEAR GATES
LINEAR MIXER
to oscilloscope
STRETCHER
ADC
SCALER
GATE GENERATOR
Other scintillator planes
Readout chambers
PATTERN UNIT
EXTERNAL INPUT
EMR 6130

FIG.4

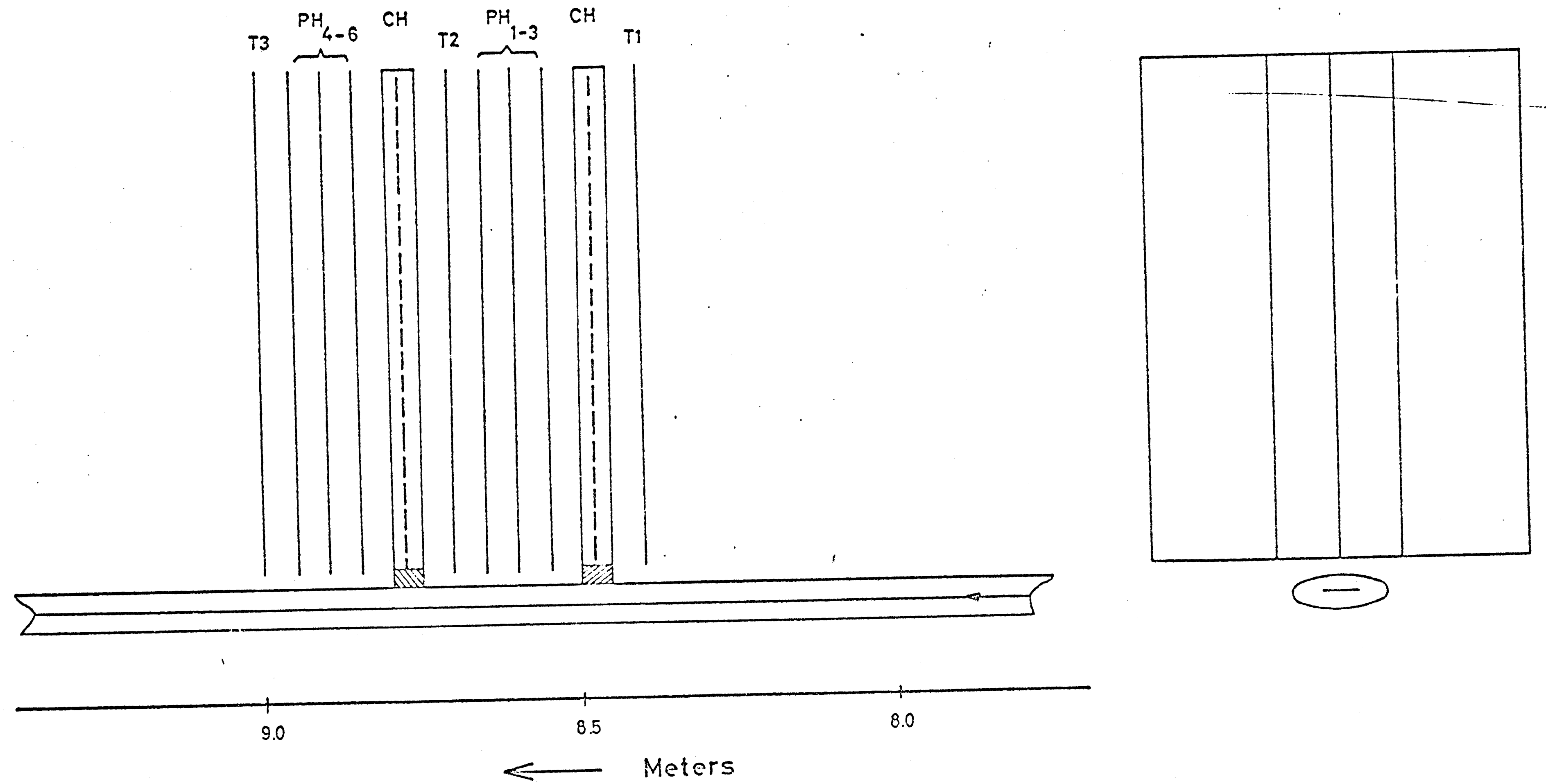


FIG. 5