Laboratori Nazionali di Frascati

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A GAMMA RAY SPECTROMETER FOR ENERGIES UP TO 1 GeV

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In order to calibrate the electron beam of the electrosynchrotron of the Italian National Laboratory in Frascati, a pair spectrometer has been designed and is now under construction. It will be operating at the beginning of 1959. The energy of the Bremsstrahlung beam of the electron synchrotron is 1000 MeV. It is possible to use this design of the pair spectrometer for electrodynamics experiments.

Below is a brief description of the different parts of the spectrometer: as
Magnet
Target which converts photons into electron pairs
Scintillation counters
Electronic equipment.

(1) The magnetic deflector, designed by ourselves, is now under construction. The total weight of the magnet is 19.000 Kg and maximum magnetic induction in the air gap of 100 ± 0.1 mm is 2 Wb/m^2.

Pole faces, which are flat and parallel, are trapezoidal in shape and are of dimensions 1100 mm and 300 mm respectively at the base — the height is 850 mm.

Current maximum is 2100 A, stabilized at 0.1 %, with 120 turns of water-cooled copper coils. The electric power is 400 kW.

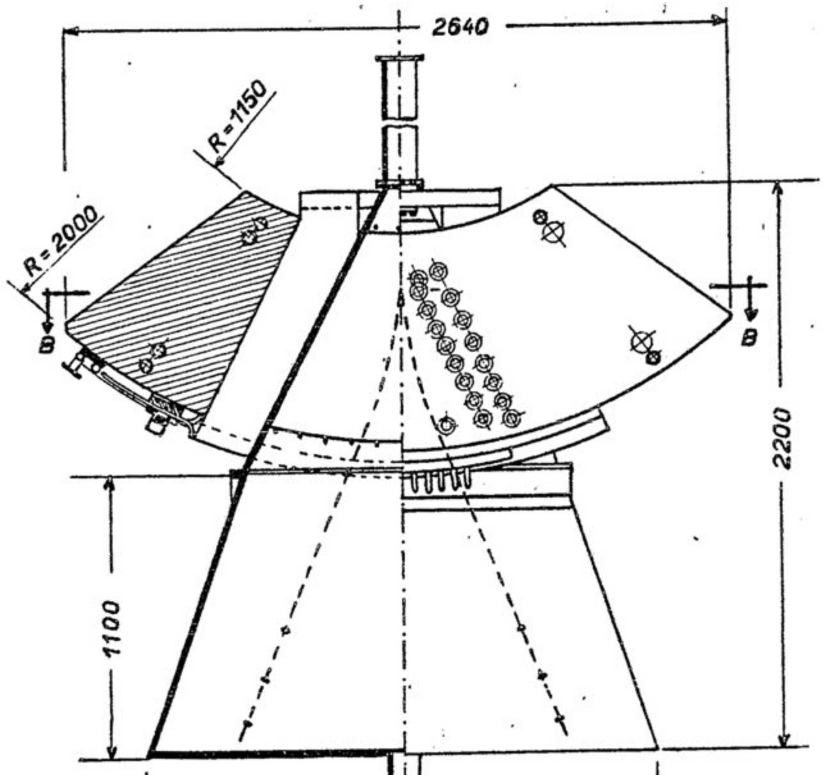

FIG. 1

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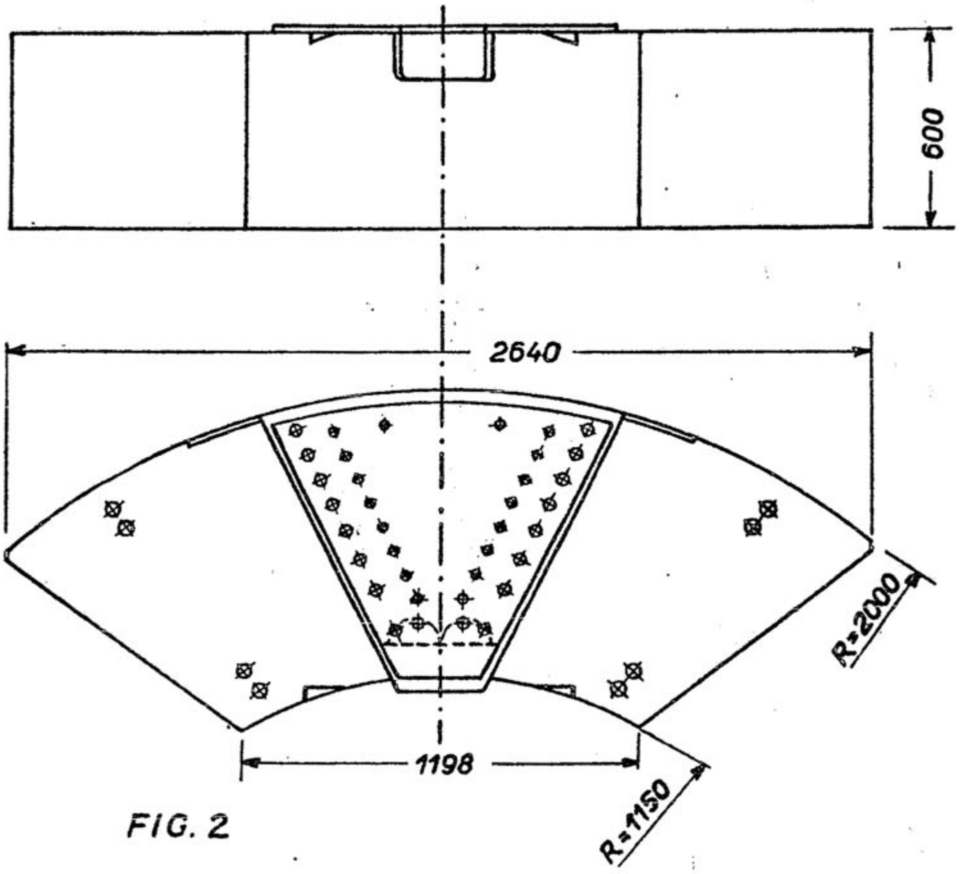


FIG. 2

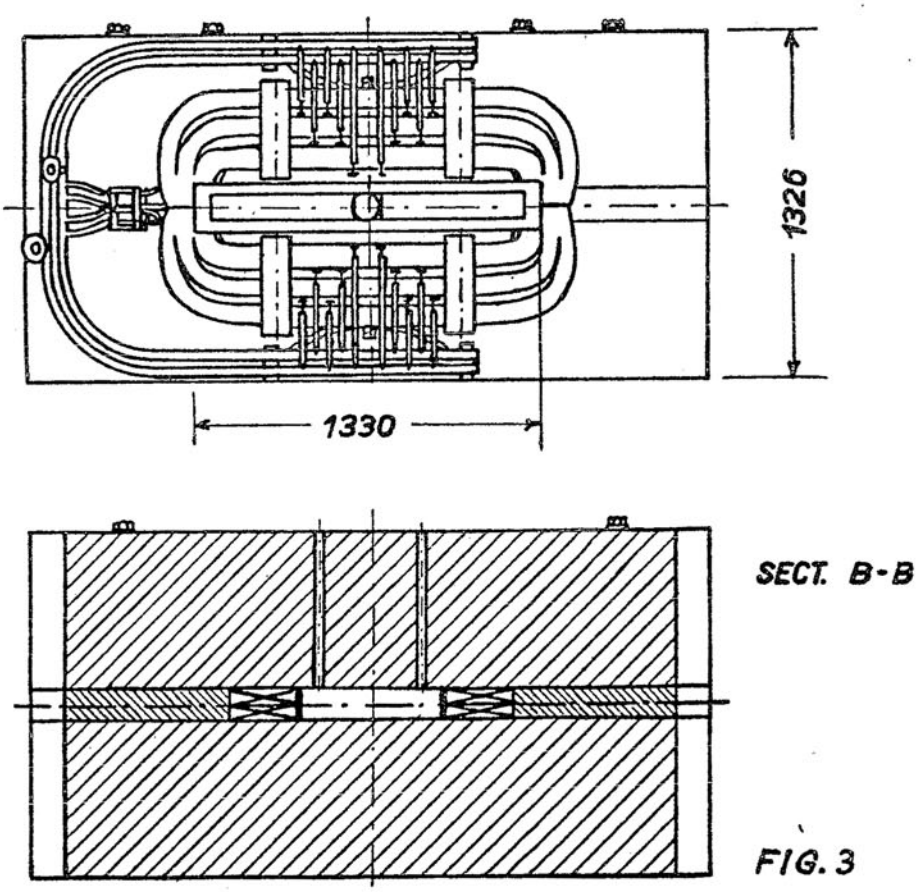


FIG. 3

The magnet is shown in Figs. 1, 2 and 3; Fig. 1 shows the upper part, in which there are 36 holes for putting scintillation counters inside the magnet. The holes have been calculated to obtain a multichannel pair spectrometer and for making electrodynamics experiments. The gap is 100 mm in height so that it should be possible to calibrate 60 mm beams. Around the gap a tank has been arranged in which a vacuum of the order of some tenth of mm Hg can be obtained.

As will be seen later the first arrangement, which is at present under construction, will consist of a single channel outside magnetic field, as shown in Fig. 1, where dotted lines indicate two symmetrical trajectories of electrons having the same energy. Figs. 4, 5 and 6 show the results of magnetic measurements made on a

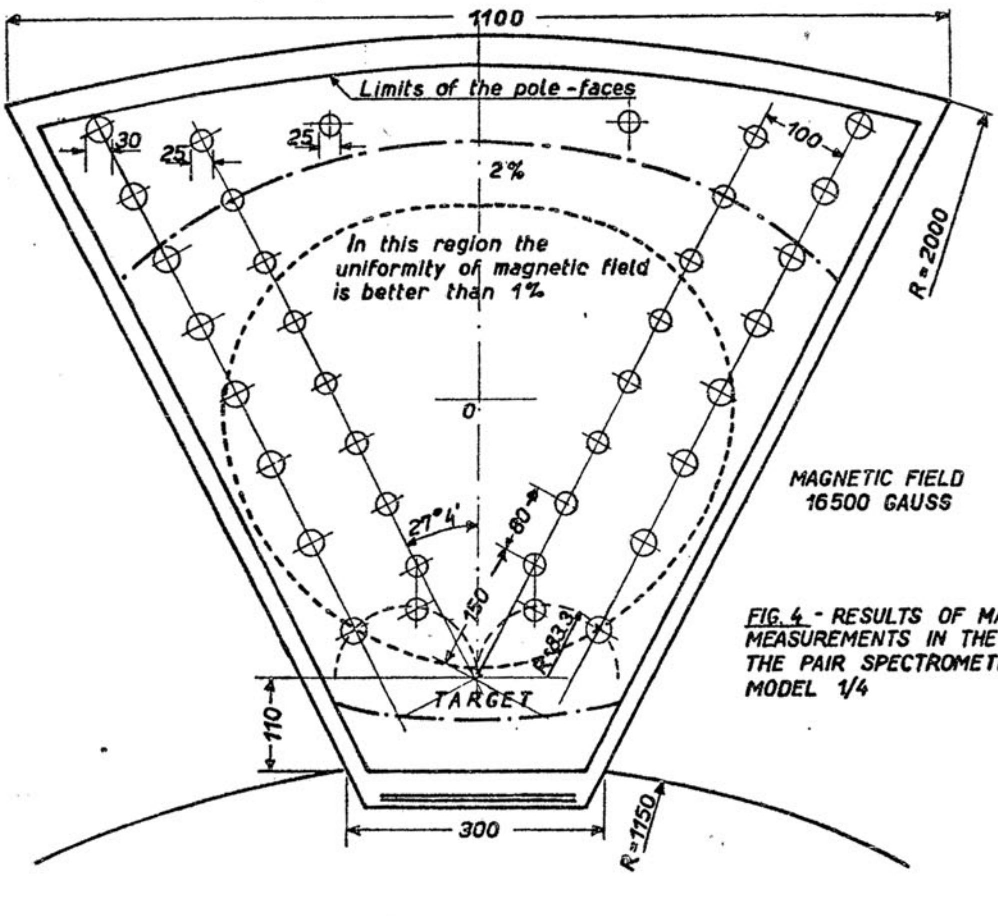


FIG. 4 - RESULTS OF MAGNETIC MEASUREMENTS IN THE GAP OF THE PAIR SPECTROMETER ON A MODEL 1/4

model of the magnet 1/4 scale. In Fig. 7 there is a picture of the model of the pair spectrometer.

(2) The target has been calculated by assuming the following hypothesis:

a) the spectrum of γ-rays is given by:

$$N(k) = \frac{\lambda N_e}{k}$$

k = energy of γ's

λ = thickness in radiation length of the electrosynchrotron target

N_e = number of electrons circulating in the beam

b) the total cross section of pair production is given by:

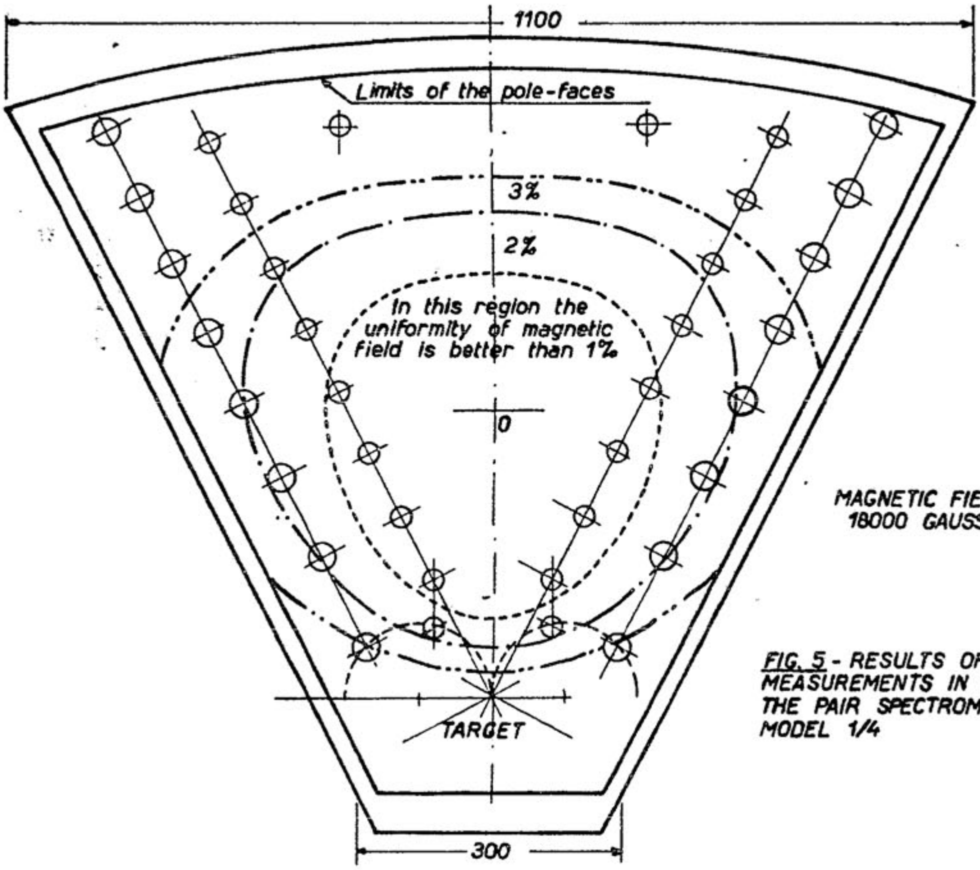


FIG. 5 - RESULTS OF MAGNETIC MEASUREMENTS IN THE GAP OF THE PAIR SPECTROMETER ON A MODEL 1/4

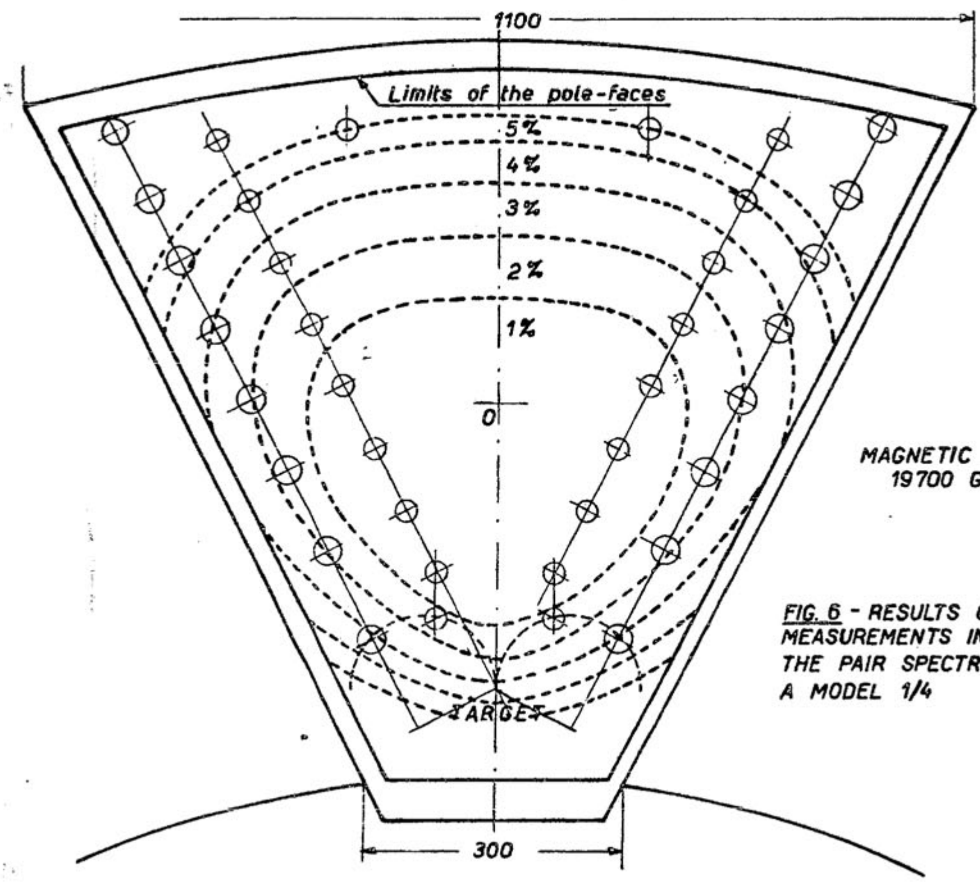
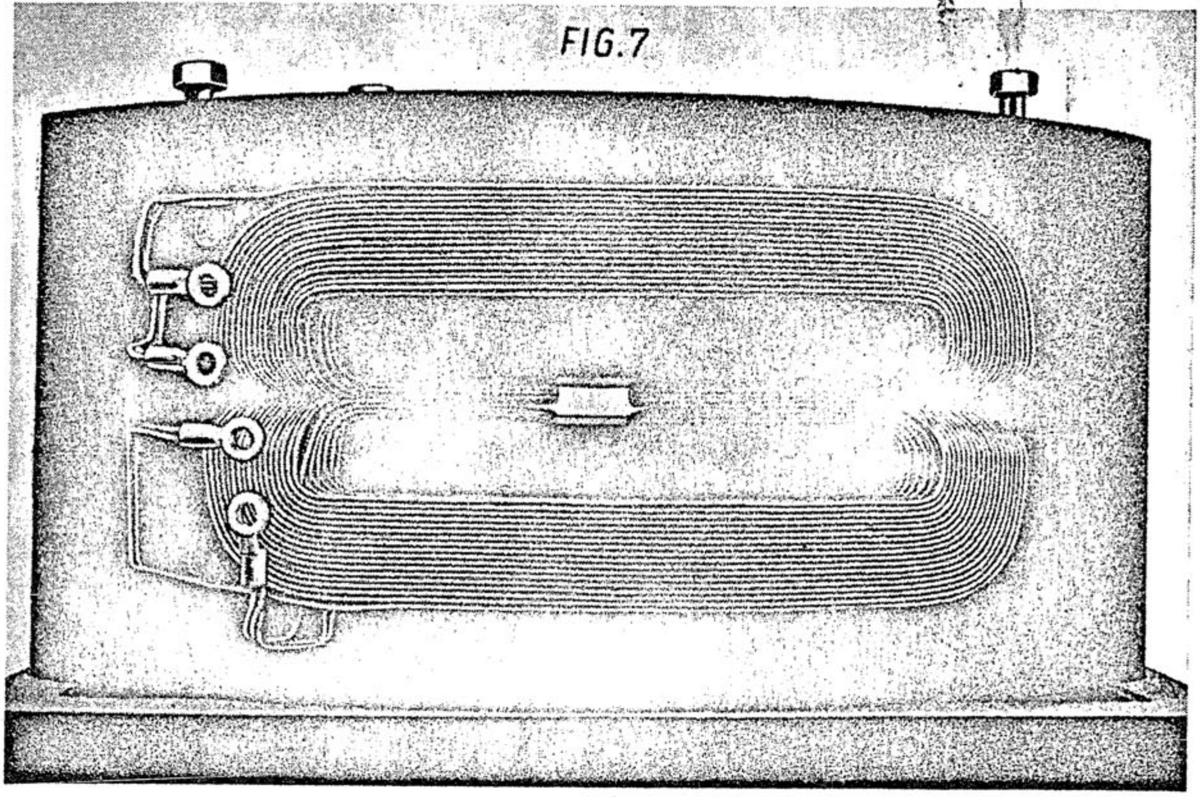


FIG. 6 - RESULTS OF MAGNETIC MEASUREMENTS IN THE GAP OF THE PAIR SPECTROMETER ON A MODEL 1/4



$$\Phi_{tot} = \frac{Z(Z+1)}{137}\left\{\frac{28}{9}\log\left(183\ Z^{-1/3}\right) - \frac{2}{27}\right\} r_0^2$$

where Z is the atomic number of the target, and

$$r_0 = \frac{e^2}{mc^2} = 2.8\times 10^{-13}\ \text{cm}.$$

Hence if the spectrometer records only pairs of the electrons having the same energy $E \pm \delta E$, we can calculate the following expression:
number of pairs of electrons having the same energy E:

$$N_p = Q\left(\frac{\delta E}{2E}\right)^2$$

number of pairs in which a single electron has energy E:

$$N_s = Q\,\frac{\delta E}{E}\left(1 - \frac{E}{K_{max}}\right)$$

where K_{max} is the maximum energy of photons, and Q is given by

$$Q = \Phi_{tot}\,\frac{A\,\rho\,\lambda\,N_e\,X}{P}$$

where

A = Avogadro's number
ρ = the density (in g/cm³) of the converter
P = the atomic weight
X = the thickness (in cm) of the converter

Let τ be the resolution time of the electronic coincidence between some counters placed along the two paths of electrons, and T the length of the electrosynchrotron pulse; the ratio between spurious coincidence $2\,\tau\,Ns^2$ and real coincidence due to two electrons of the same energy per second is given by

$$\eta = 8\,\tau \frac{Q}{T}\left(1 - \frac{E}{K_{max}}\right)^2.$$

By assuming reasonable values, for example

$N_e = 10^9$ electron per pulse $\quad\quad \lambda = 2\times 10^2$

$X = 10^{-3}$ cm of Al $\quad\quad \tau = 0.01\ \mu s = 10$ ns

$T = 500\ \mu s$

we easily find

$$N_p = 130\,\lambda^{-1} = 0.65 \text{ counts per pulse}$$

$$N_s = \begin{cases} 5.2\times 10^4\ \lambda^{-1} = 26 \text{ counts per pulse for E} = 0 \\ 1.3\times 10^4\ \lambda^{-1} = 6.5 \text{ counts per pulse for E} = 500 \text{ MeV} \end{cases}$$

That means for η the following numbers:

$$\eta = \begin{cases} 10\% & \text{for E} = 500 \text{ MeV} \\ 40\% & \text{for E} = 0 \end{cases}$$

Therefore, the counting rate of random coincidences is quite high even if the electronic coincidence has high resolution, and is strongly energy dependent; in addition, we have to calculate background counts due to different particles and photons which cross the counters.

(3) As a consequence of the preceding remarks we have designed the arrangement shown in Fig. 1. Two different threefold coincidences separately record each electron of a given energy, which depends on the magnetic field. Resolution time of each coincidence is of the order of 5 ns and random coincidences due to background particles crossing the counters separately are quite negligible. The first and the second scintillation counters determine the energy spread due to energy loss and scattering of electrons inside the counters; for that reason they have to be as thin as possible, but thick enough to give a reasonable amount of photons. A good compromise seems to be a thickness of the order of 1 mm, which corresponds to an energy loss of the order of 0.3 MeV.

The arrangement designed has some advantages:

a) background coincidences are quite negligible;
b) the arrangement is much simpler because the scintillation counters are outside the magnetic field and photomultipliers can be put directly into contact with the scintillators;
c) the possibility of simultaneously measuring the real coincidences due to electron pairs of given energy, and the random coincidences due to different electron pairs each having a single electron of the right energy. This can be done very easily by simultaneously measuring the prompt and delayed coincidences between pulses coming from the two three-fold coincidences, as shown in Fig. 1.

Therefore, the difference between prompt and delayed coincidences gives the correct number of pairs of electrons having the same energy as a function of the energy, which depends on the magnetic field, i.e. on the current energizing the magnetic deflector.

Of course, we have to pay for these advantages: we must, indeed, take into account the effect of the fringing field, and correct by using conventional methods, for example the floating wire method for testing electron trajectories and resolution of the apparatus.

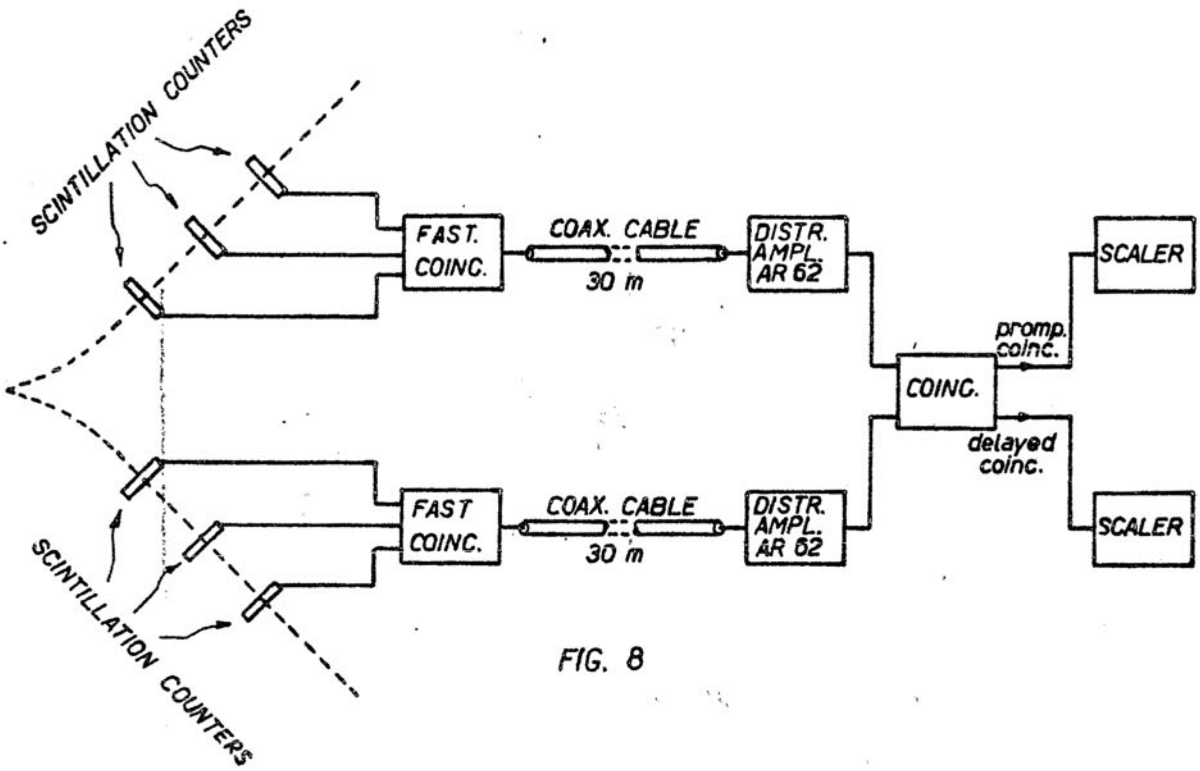


FIG. 8

(4) The block diagram of electronics is shown in Fig. 8. Three-fold coincidences are obtained by means of the circuit shown in Fig. 9. The anodes of the tubes E180F are connected in parallel by means of inductances which form with stray capacitances an artificial transmission line of characteristic impedance Z_0 and delay per section τ_0.

The grids of the tubes are connected to the anodes of photomultipliers by means of a coaxial cable of characteristic impedance Z_0 terminated with a pulse forming cable shorted at the end; the cables connecting photomultipliers and tubes are slightly different in length for compensating the delay introduced by one section of the line between the anodes. Negative pulses of photomultipliers cut off the tubes, and if all tubes are cut off one after the other, with time delay just equal to τ_0, all positive pulses on the anode line will arrive at the end at the same time, giving rise to a pulse whose amplitude is 3 or 1.5 times the amplitude of the pulses given by single or two-fold coincidences. The resolving time of this circuit can be made easily of the order of 2—3 ns[4]). Both three-fold coincidences are placed near the electrosynchrotron and the inputs are directly connected to the anodes of RCA 6810A photomultipliers by means of coaxial cables. The outputs are brought out by means of coaxial cables to the control room which is situated at about 30 m and where all electronic equipment is located.

[4]) This circuit has been described in Nuovo Cim., 9, 171 (1958).

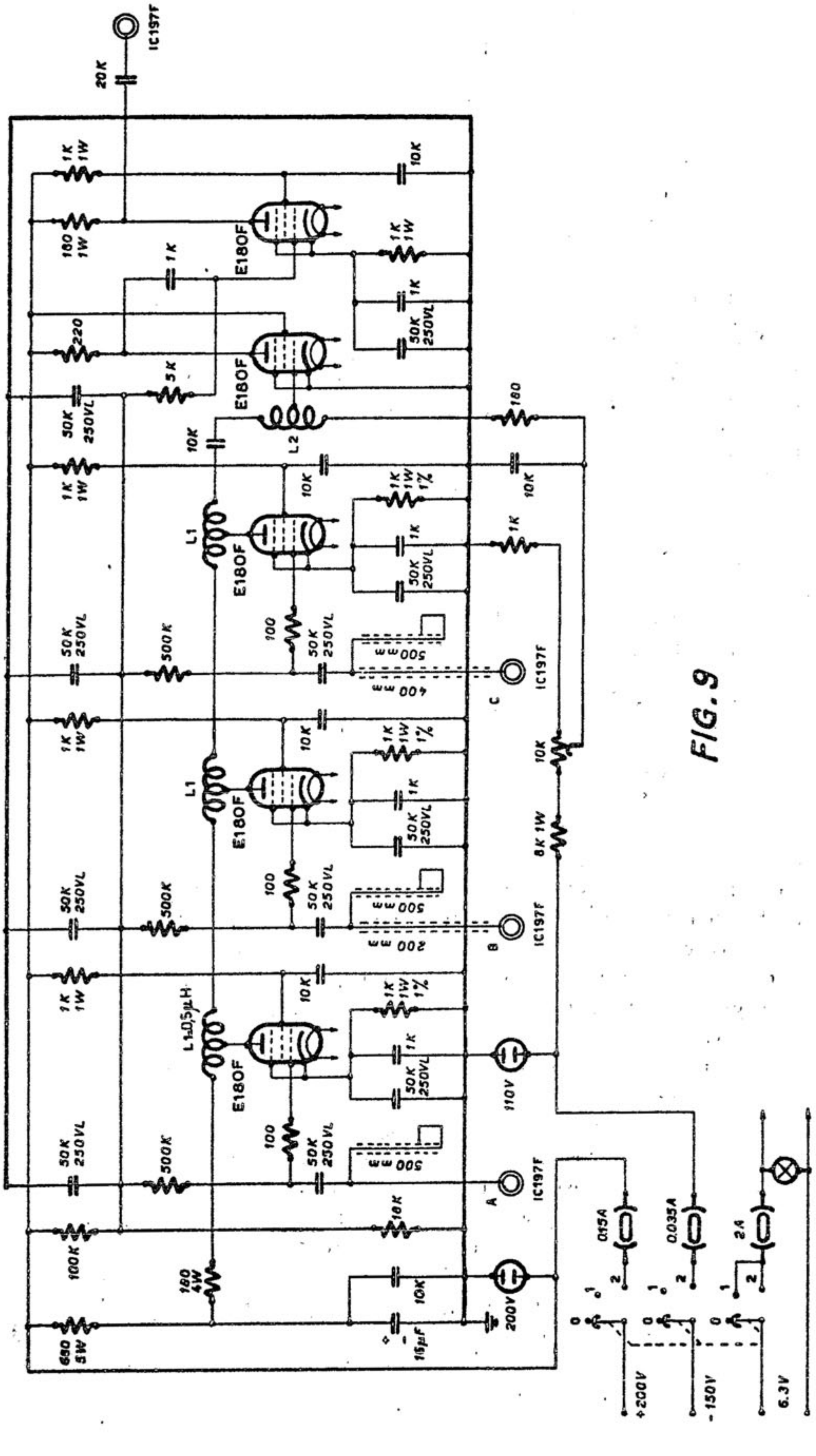

IC197F
20 K
1 K 1W
180 1W
10 K
E180F
220
5 K
50 K 250VL
L2
L1
L1=0,5µH
100
500 K
180
1 K 1W 1%
500 mm
400 mm
200 mm
A
B
C
10 K
8 K 1W
110V
200V
100 K
16 K
180 4W
680 5W
15µF
0.15A
0.035A
2A
+200V
-150V
6.3V

FIG. 9

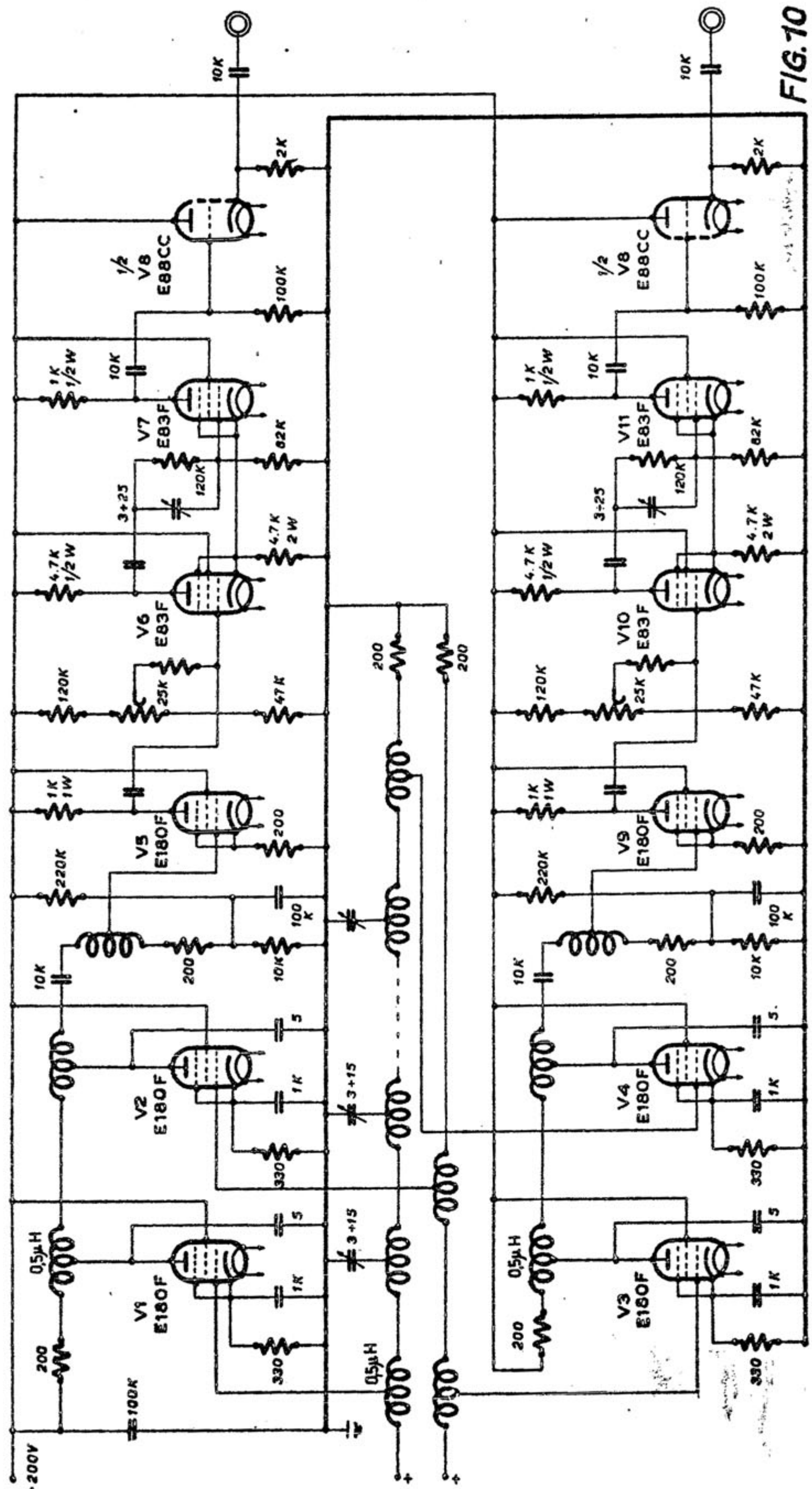

+200V
V1 E180F
V2 E180F
V3 E180F
V4 E180F
V5 E180F
V6 E83F
V7 E83F
½ V8 E88CC
V9 E180F
V10 E83F
V11 E83F

FIG. 10

As Fig. 8 shows, the three-fold coincidences feed two distributed amplifiers, whose outputs are connected to the inputs of the "prompt and delayed coincidences". The amplifiers used for this purpose are the "fast amplifiers," mod. AR62 produced by "Italelettronica", having the following characteristics: input and output impedance 200 Ohm; gain 31.6 db when output is matched; rise time 3.5 ns.

The prompt and delayed coincidences are shown in Fig. 10; the inputs are connected to two lumped delay lines of the same characteristic impedance 200 Ohm but having different numbers of sections. Using the circuit just described, one gets the pulses for prompt coincidence (tubes V_1, V_2) from the same lines and for delayed coincidences (tubes V_3, V_4). The resolving time is about 5 ns and the delay is of order of 20 ns. The outputs of these coincidence circuits are quite conventional and connected to scalers and counting circuits.