MUON COUNTER

by

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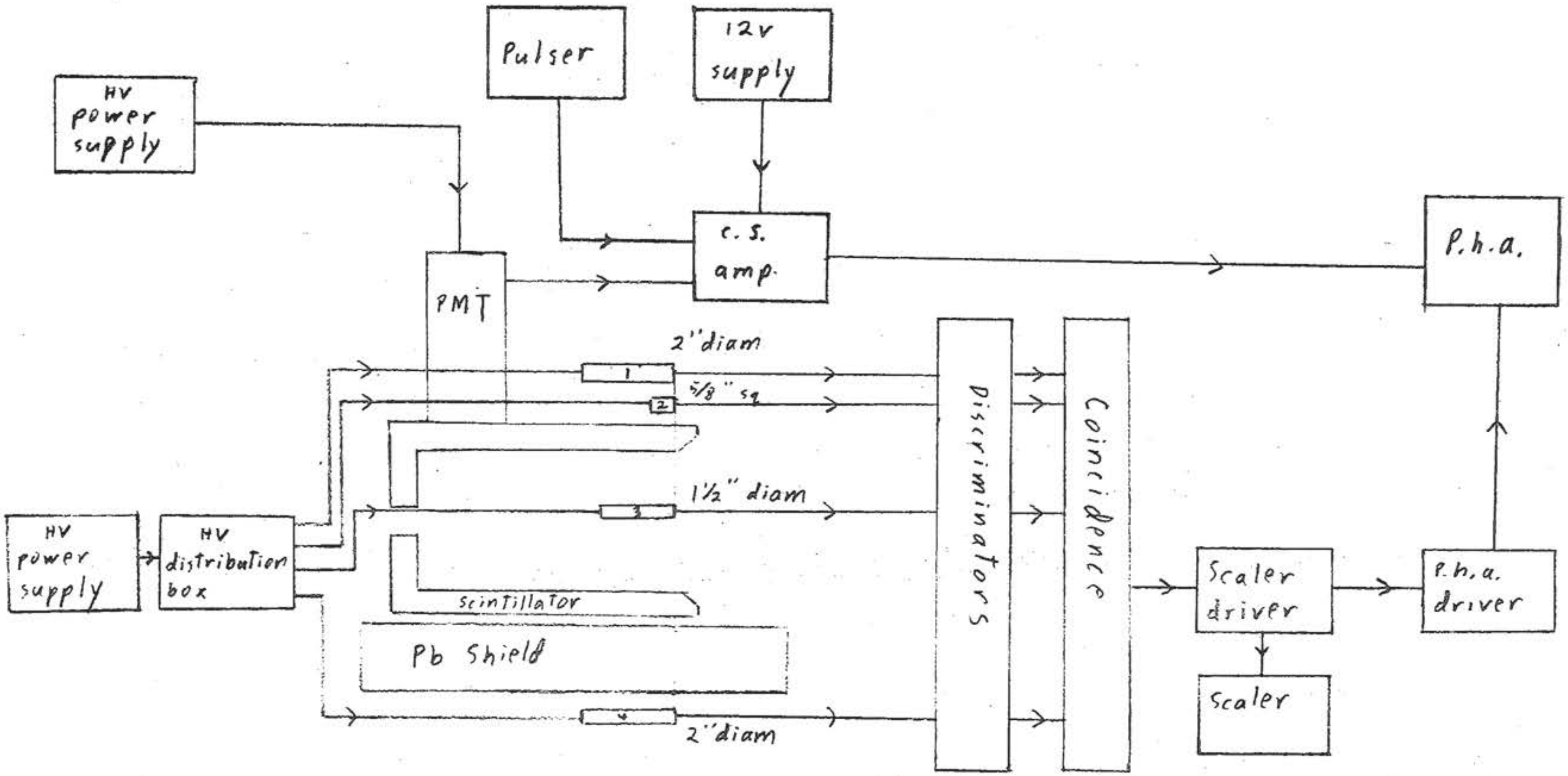
INTRODUCTION

This report will describe how the muon counters and associated electronics are used to determine the voltage setting for the photomultiplier tube looking at the anticoincidence cup (D11) on the IMP H and J experiments. The function of the counters and electronics will be described in enough detail to enable the reader to use them for other purposes.

Figure 1 shows an electrical schematic for the set up to be used. The scintillators marked #1, 2, 3, 4 are the scintillators for the muon counters. A muon counter is an assembly consisting of a scintillator connected to a photomultiplier tube by a light pipe. The scintillators (of the muon counters and the IMP anticoincidence cup) should be aligned in such a manner as to allow a charged particle travelling in a straight line to trigger all of them.

The voltage on the phototube looking at D11 must be set high enough so that the charge at the anode of the phototube will exceed the 1.4 pc discriminator threshold on the IMP experiment, when a minimum ionizing particle passes through D11. With the set up as in Figure 1, the pulse height analyzer gate will open only when a relativistic charged particle (usually a muon) passes through the scintillator anticoincidence cup. Most of the charged cosmic radiation at sea level consists of muons. To trigger all the counters the muon must be relativistic and therefore approximately minimum ionizing since it takes at least a 60 Mev muon to penetrate the lead shield.



1,2,3,4 are scintillators for muon counters
Scintillator and muon counter scintillators shown in cross section

Fig. 1

SCHEMATIC OF SET UP

The coincidence requirement eliminates noise events, spurious low energy radiation, accidental coincidences between fewer than all 4 muon counters, and γ events (since the probability of γ interaction with each scintillator is small). Note: Since most muons are incident from the vertical direction[1] the muon counters should be lined up vertically for the greatest count rate.

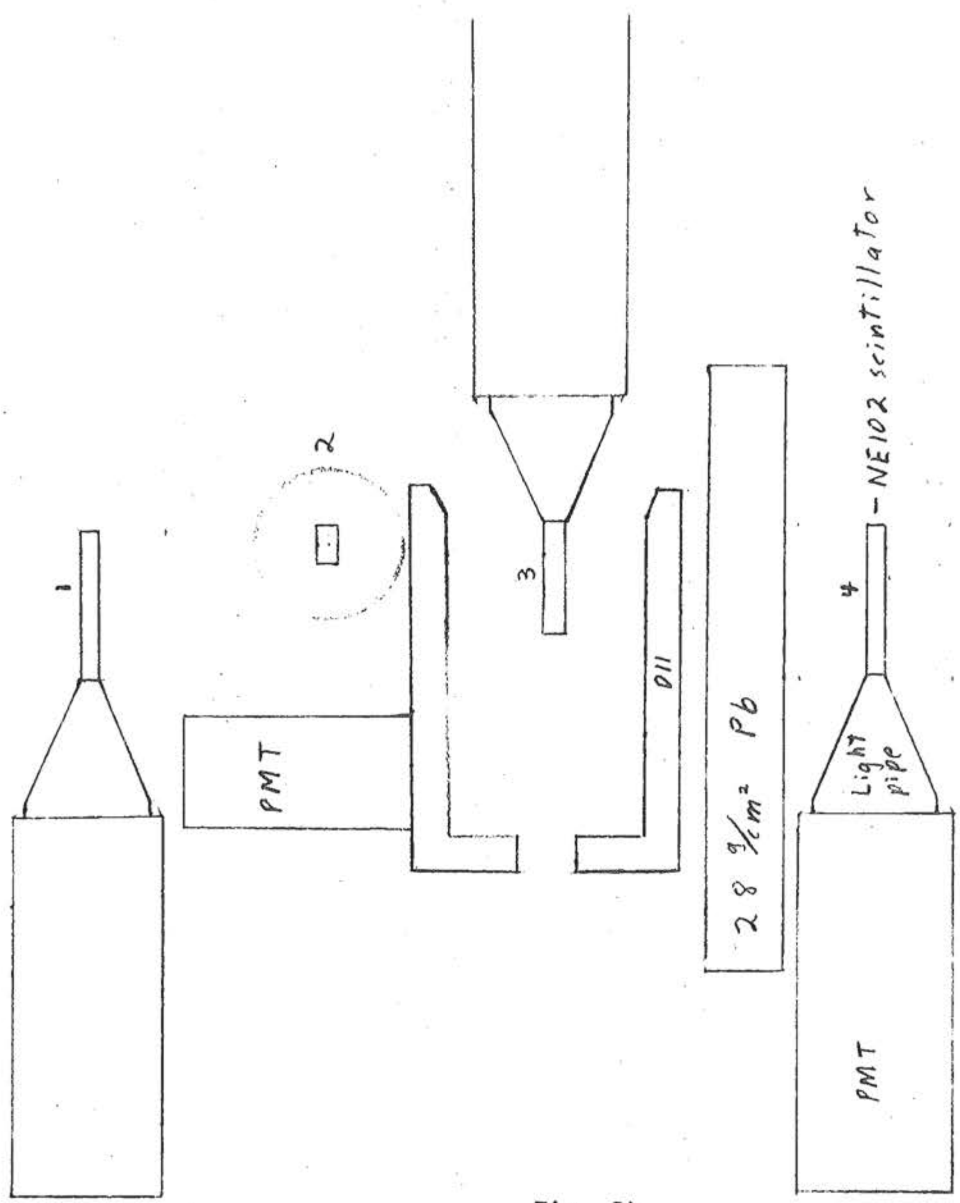


Fig. 1b

APPARATUS

The muon counters are preassembled packages consisting of a 1/4" thick NE 102 scintillator connected to a photomultiplier tube by a lucite light pipe. The scintillator-light pipe junction is epoxied while the phototube-light pipe junction consists of Dow-Corning coupling compound #20-057. A schematic diagram of a counter is shown in Figure 2 and a wiring diagram for the photomultiplier tube is shown in Figure 3. The cables from the counters to the discriminators should be approxmiately the same length since the electron transit times of the various photomultiplier tubes are within several nanoseconds of each other, and fast electronics is used. If there are any problems with reflections from the end of the signal cable, the second anode output of the photomultiplier tube can be terminated with 50 Ω. The voltage on the tube will have to be increased since the output is now cut in half.

CAUTION: The maximum voltage rating of the photomultiplier tube is 2600 v.

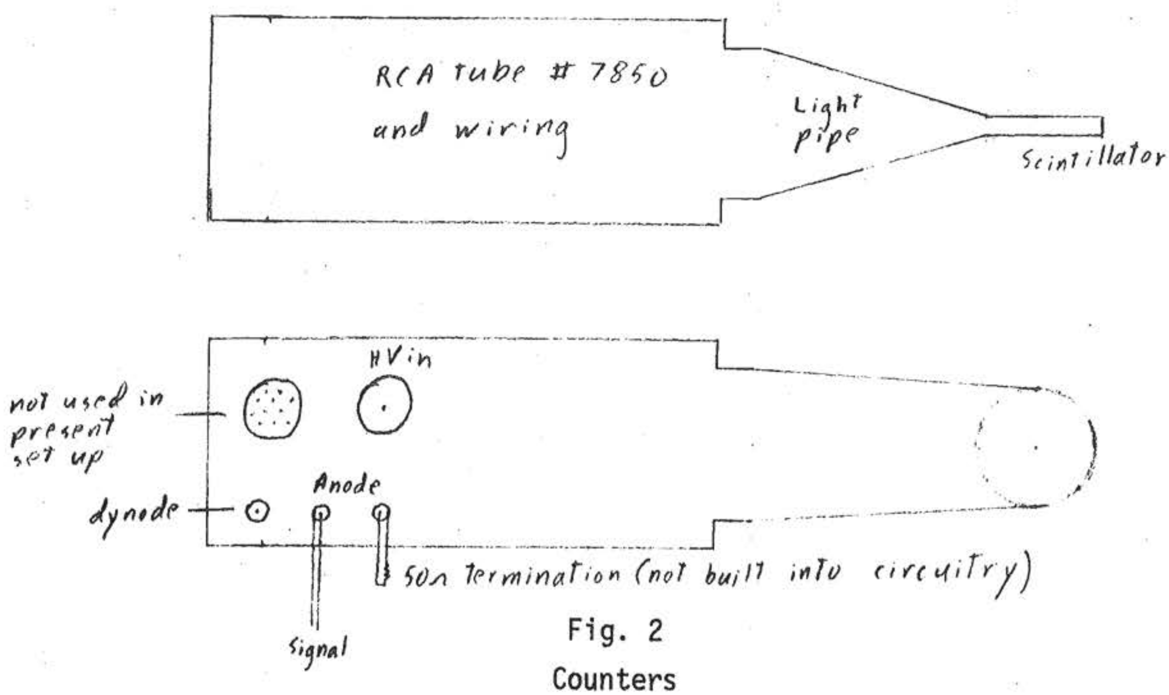


Fig. 2
Counters

Typical Wiring Diagram of Base of Tube in Muon Counter

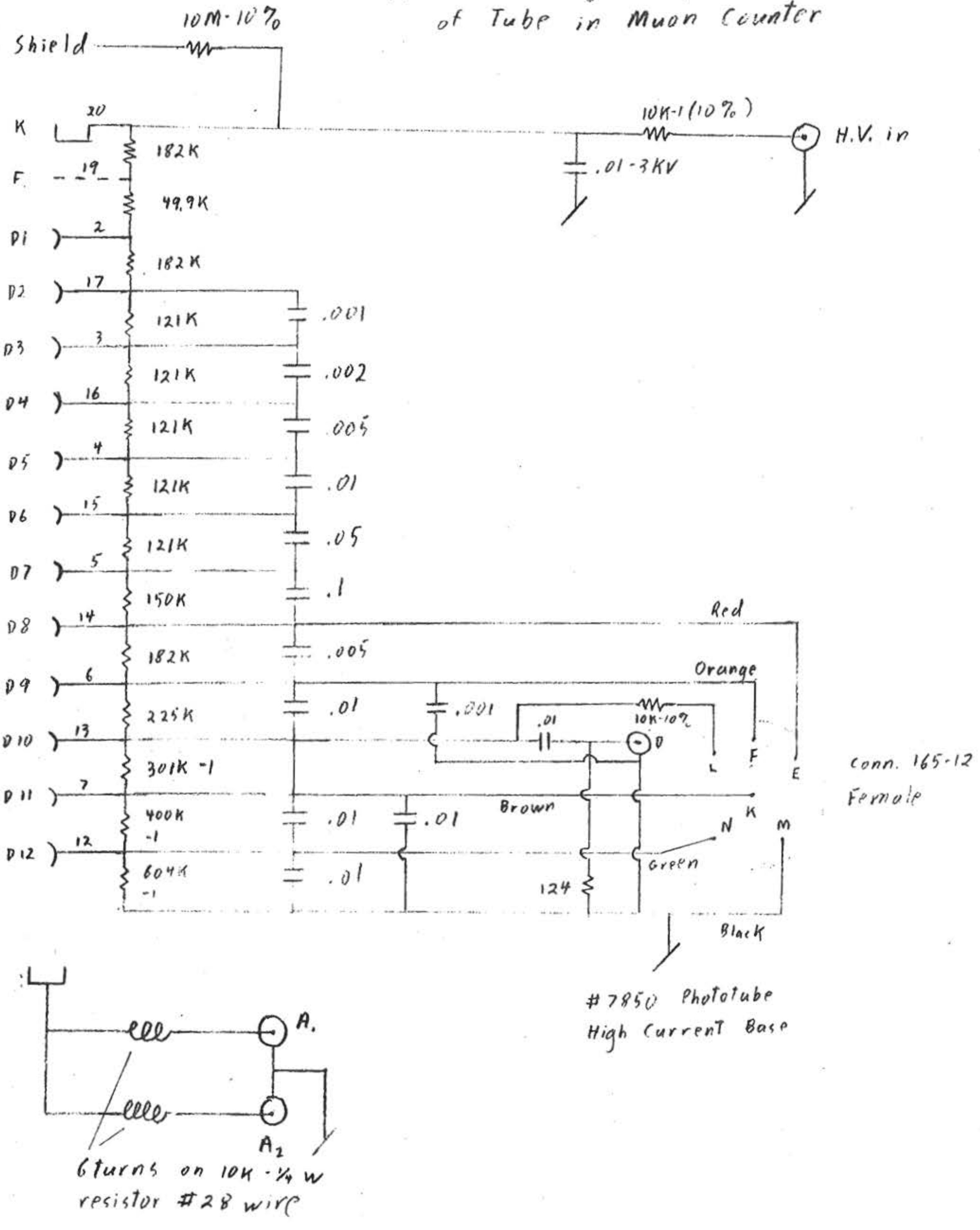


Fig. 3

Electronics:

1) 50 Ω cables should be used, and all terminations are 50 Ω. The output of a counter should be terminated if it goes into something other than the discriminator or the amplifier.

2) When the output of a counter is being disconnected from a piece of equipment, the high voltage on the counter should be off.

3) There are several high voltage distribution boxes, discriminators, and coincidence circuits available. I shall describe the ones I used. Manuals for the other discriminators and coincidence circuits can be found in the laboratory.

a) Power supply used was HV-1544 by Power Designs Pacific, Inc.

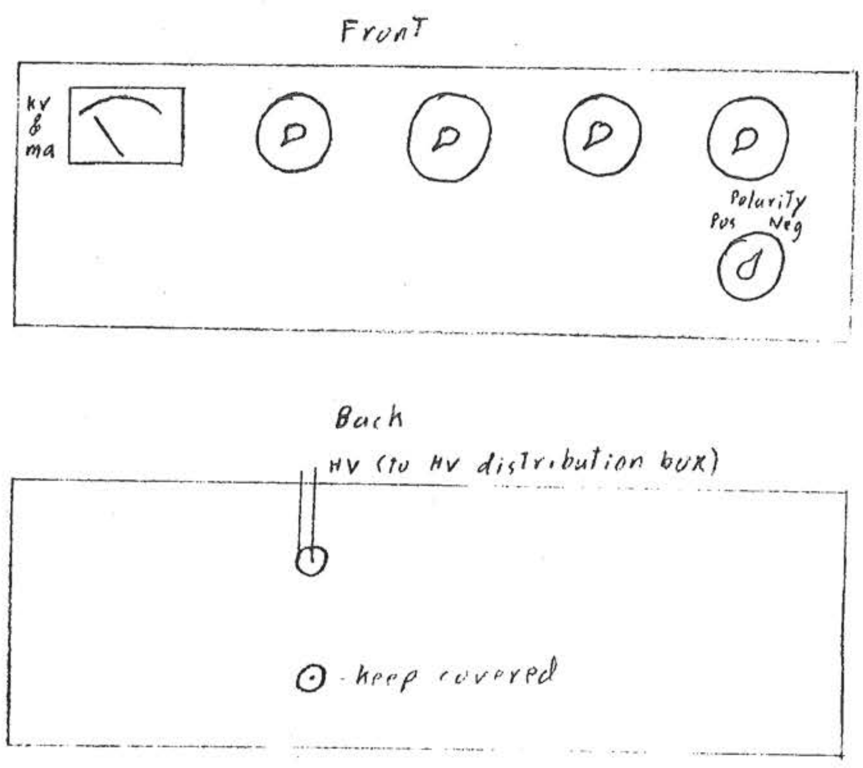


Fig. 4 Power Supply

An instruction manual for this power supply can be found in the instrument files.

b) High voltage distribution box.

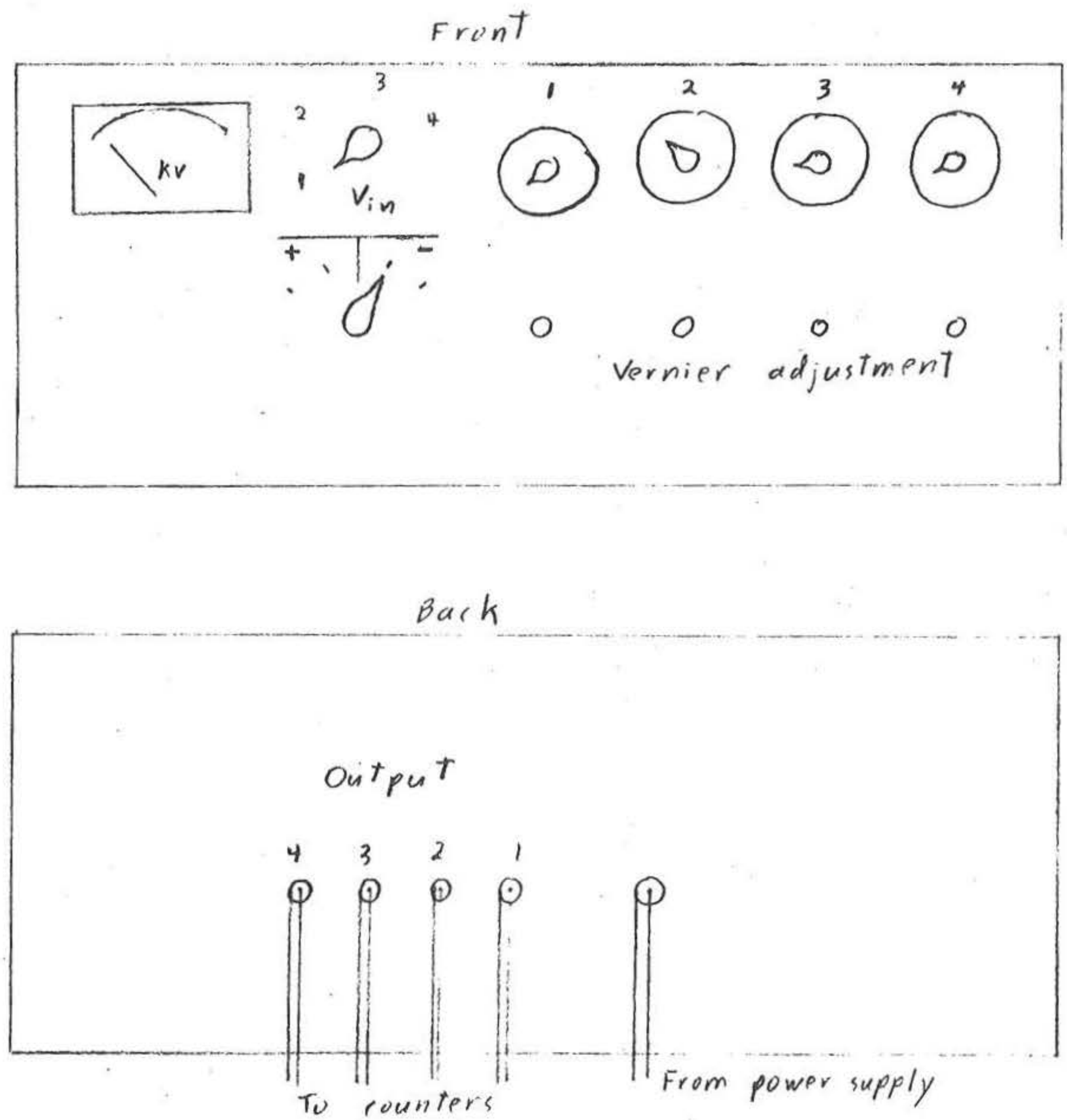


Fig. 5 High Voltage Distribution Box

c) Model T 105/N EG&G discriminator

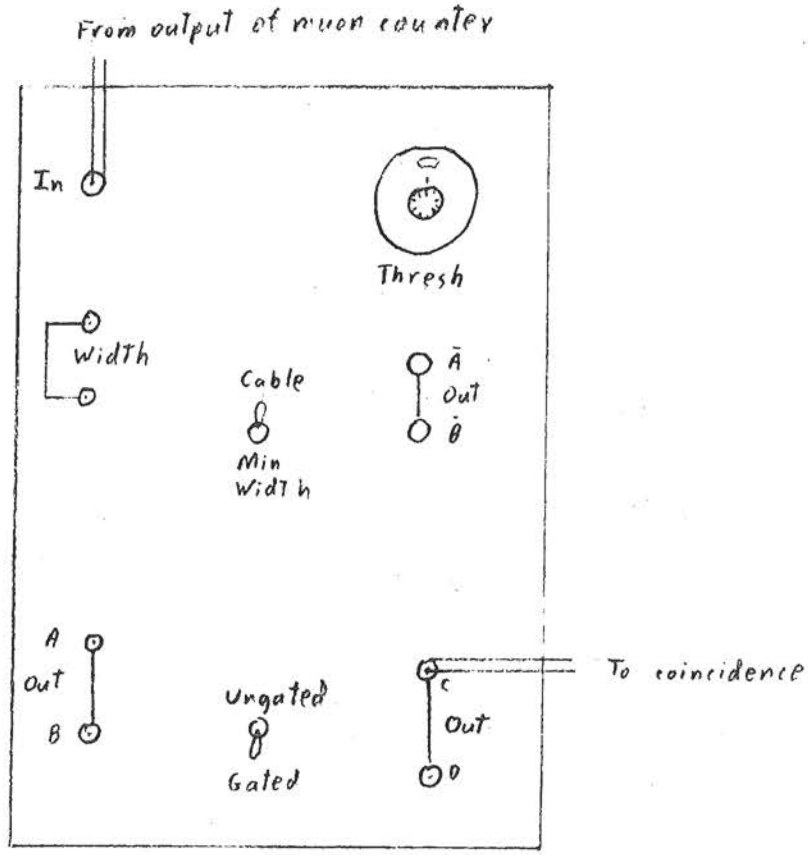


Fig. 6 Discriminator

Unused B. N. C. connectors should be 50 Ω terminated. The width of the output signal is determined by the time it takes a signal to travel the length of a cable between the connections marked "width" (∿ 4 nsec. + ∿ 1 1/2 $\frac{\text{nsec.}}{\text{ft.}}$). The discriminator threshold can be varied between 50 and 1050 mv. An instruction manual for this discriminator can be found in the laboratory.

d) Model C104A/N EG&G coincidence

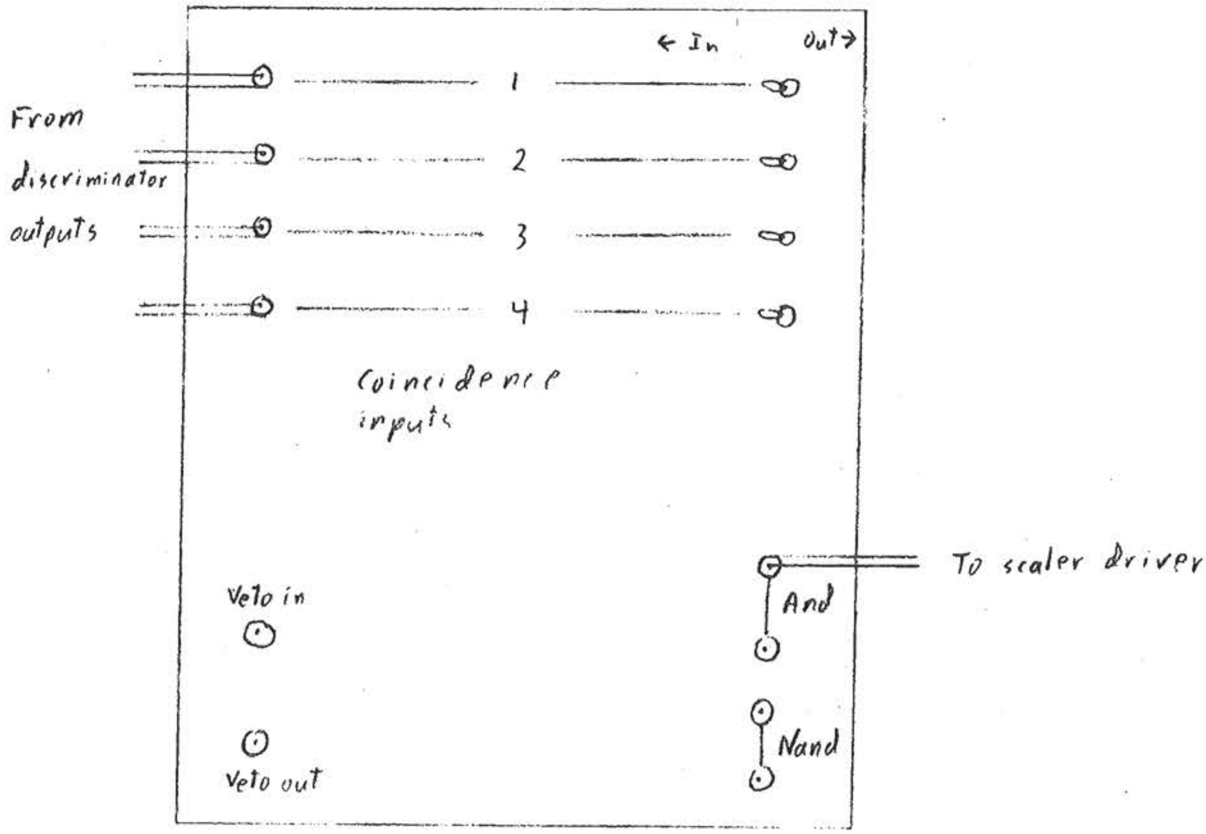


Fig. 7 Coincidence

Unused B. N. C. connectors should be 50 Ω terminated. An instruction manual for the coincidence circuit can be found in the laboratory.

e) Model DS104/N EG&G scaler driver

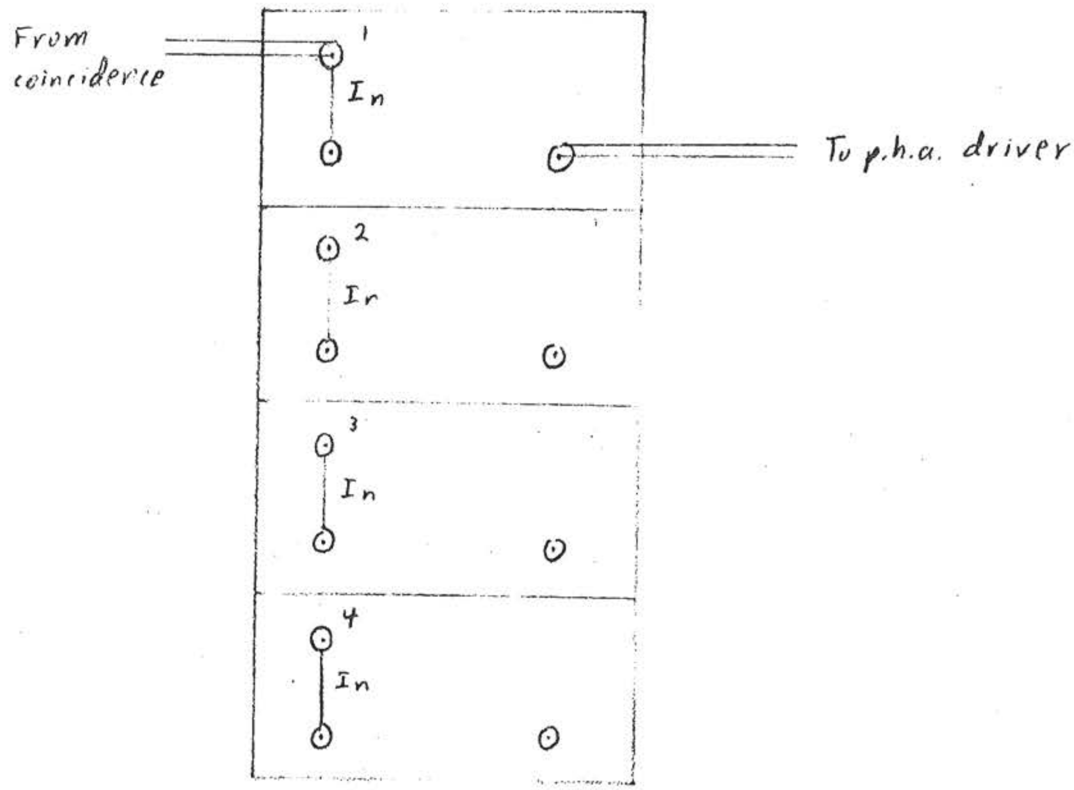


Fig. 8 Scaler Driver

Unused B. N. C. connectors should be 50 Ω terminated. An instruction manual for the instrument exists in the laboratory.

f) P.h.a. coincidence driver

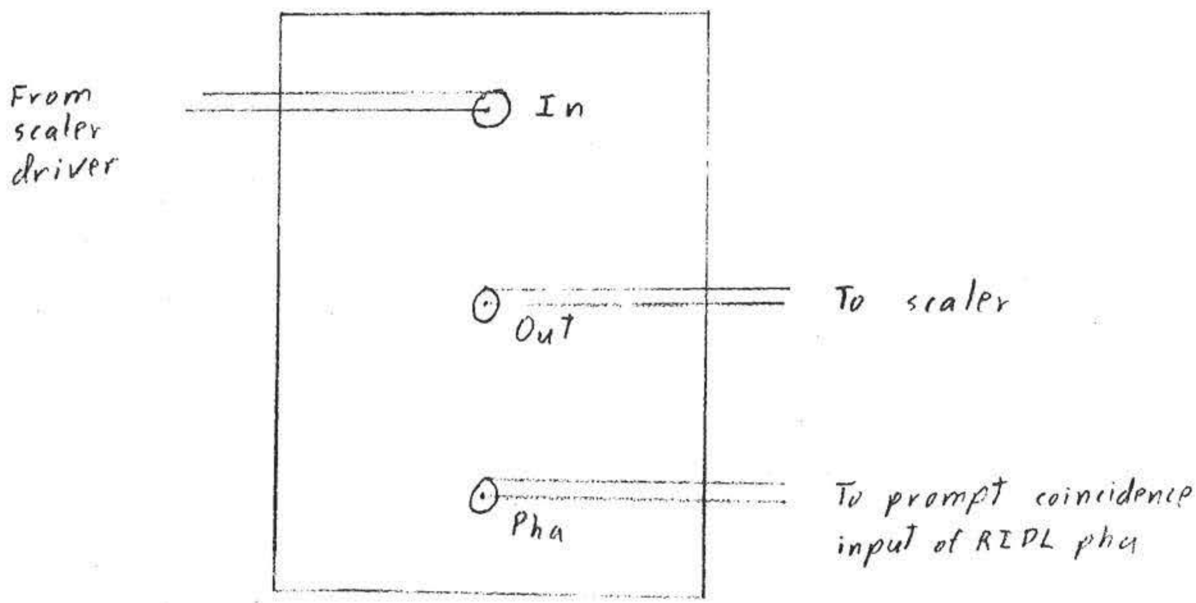


Fig. 9 P.H.A. Driver

The Terminal marked out reproduces the input signal.

g) Charge sensitive amplifier (designed by W. E. Althouse)

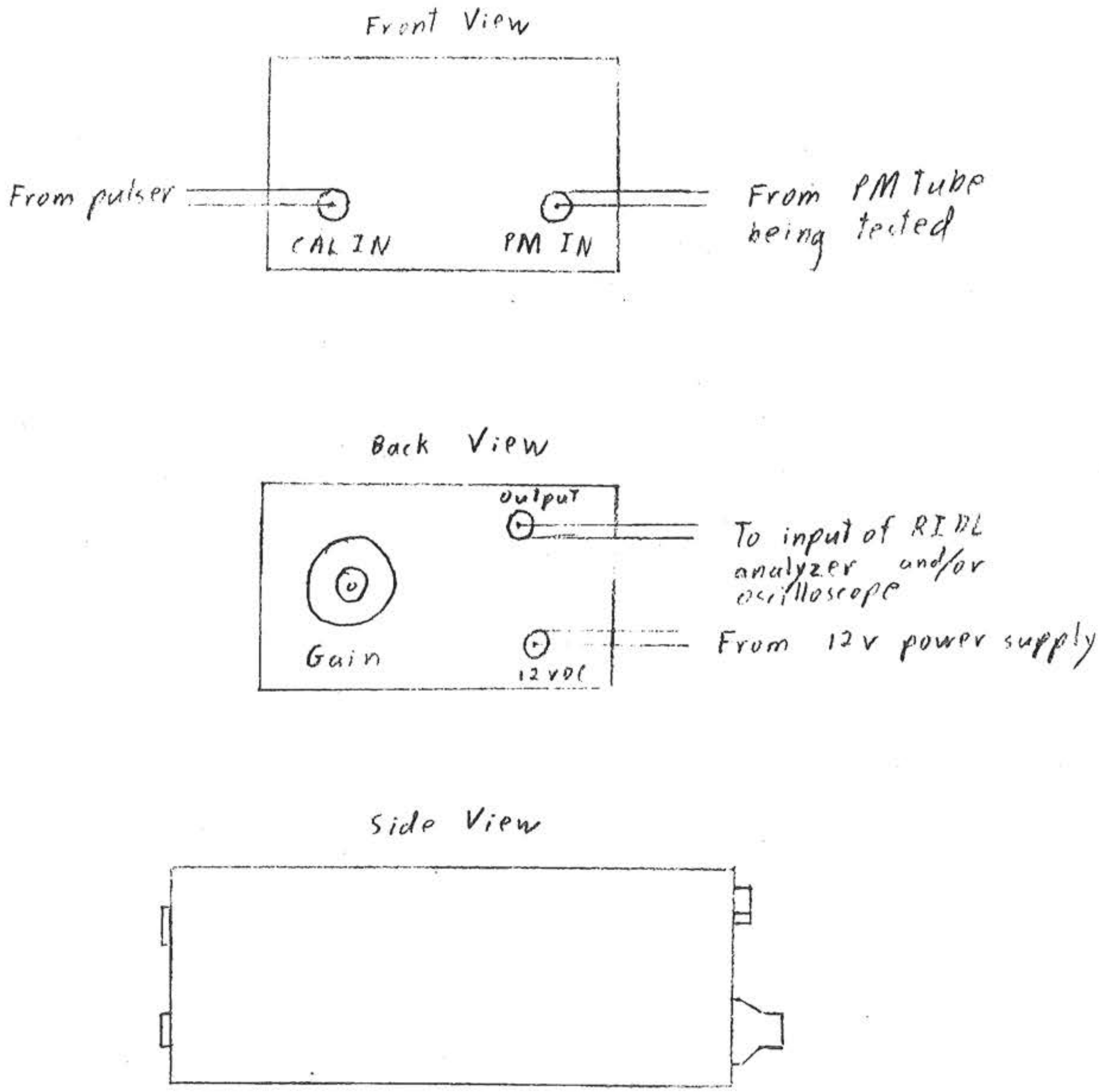


Fig. 10

Charge Sensitive Amplifier

The amplifier has a 220 p f capacitor at the calibration input.

h) Ortec 204 precision pulse generator

This pulser is used for calibration and to convert the output of the phototube as observed on the pulse height analyzer from channels to units of charge.

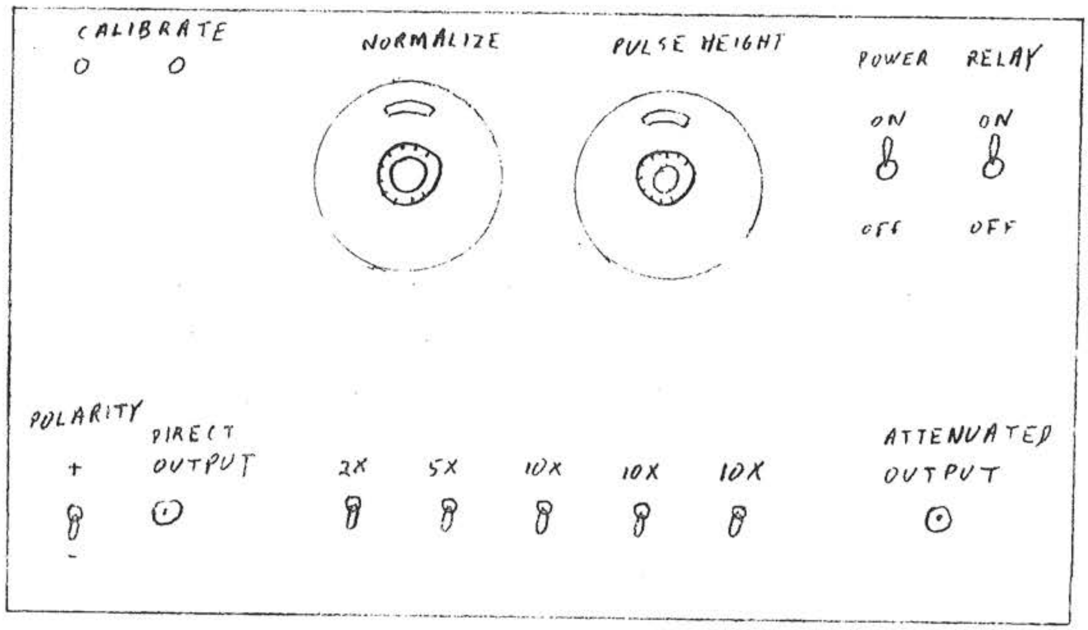


Fig. 11

An instruction manual can be found in the files in room 227.

i) R.I.D.L. pulse height analyzer.

A complete instruction manual can be found for this instrument. In the present mode of operation, the output of the p.h.a. driver goes into the prompt coincidence input of the analyzer. The coincidence switch is in the prompt position. The output of the charge sensitive amplifier goes into the direct input, but the amplifier input can also be used if the signal is too weak.

j) Amplifier for muon counter.

This amplifier is used when the pulse height spectrum from a counter is needed. It amplifies and shapes the signal from a muon counter before it goes into the R.I.D.L. analyzer input.

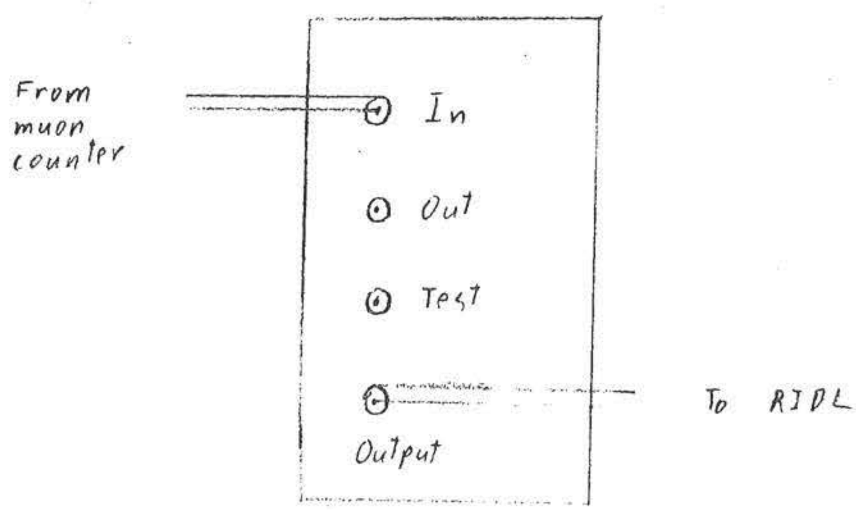


Fig. 12

The duration of the pulse from the counter is too short for it to be seen by the R.I.D.L. analyzer. One of the amplifier's functions is to lengthen the pulse.

When the apparatus is set up as in the schematic diagram in Figure 1, the signal from one counter can be followed from the output of the muon counters to the prompt coincidence input of the R.I.D.L. analyzer. A fast oscilloscope should be used. Plug-in unit 86 on a 581A scope has a preamp rise time of 2.2 nsec for 0.01-2. $\frac{v}{cm}$. All signals should be 50 Ω terminated before going through the input of the oscilloscope.

The output signal, followed from a single muon counter through the various electronic apparatus, is shown in Figures 12 through 16. The counter used has a 2" diameter scintillator. 1900 v is applied to the counter's phototube, and the second anode is 50 Ω terminated. A Co^{60} source is placed near the scintillator to give a reasonably high count rate. The anticoincidence cup is near the counter.

The output from the muon counter is shown in Figure 13.

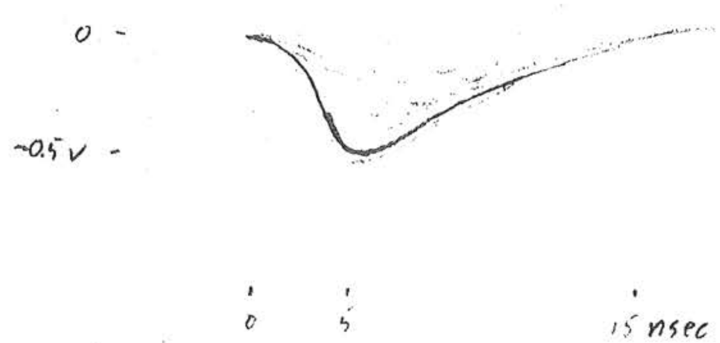


Fig. 13

The discriminator is at 200 mv. The width of the discriminator's output is set with a cable about 30 feet long. The output from the discriminator is shown in Figure 14.

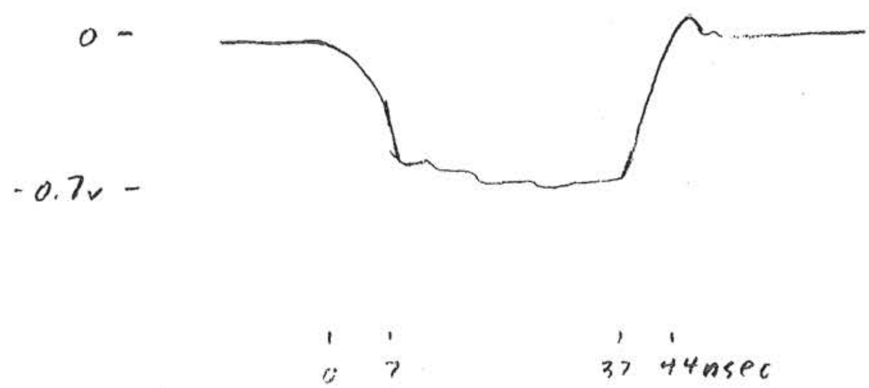


Fig. 14

Only one channel of the coincidence circuit is used in this case. The switches for the other channels are in the out position.

The coincidence output is shown in Figure 15.

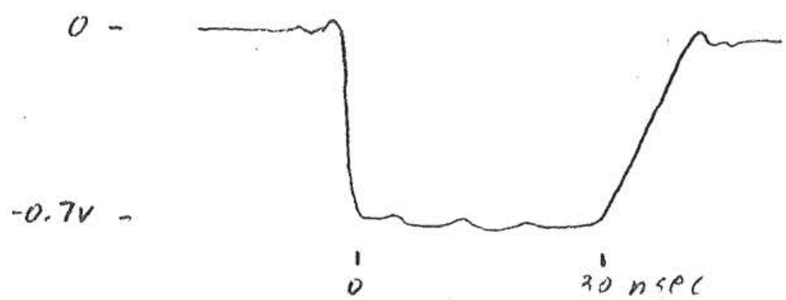


Fig. 15

This is the same as the discriminator output.

Scaler driver output:

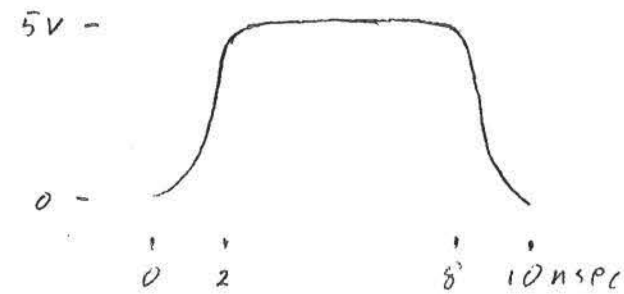


Fig. 16

P.h.a. driver output:

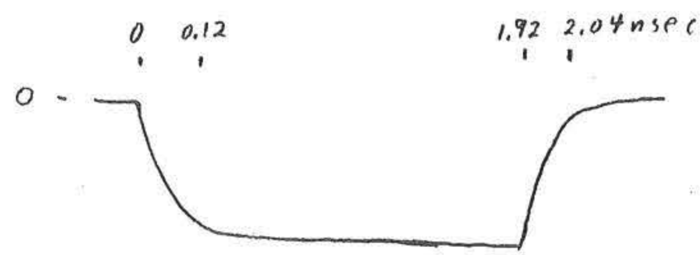


Fig. 17

Output of the charge sensitive amplifier:

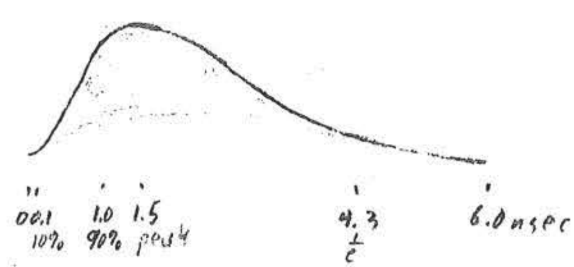


Fig. 18

COUNTER OUTPUT

If the output of a counter is analyzed by the R.I.D.L. (using the amplifier to shape the pulses going into the R.I.D.L), almost all of the events seen will be either tube noise or low energy radiation. From here on both these events will be referred to as noise.

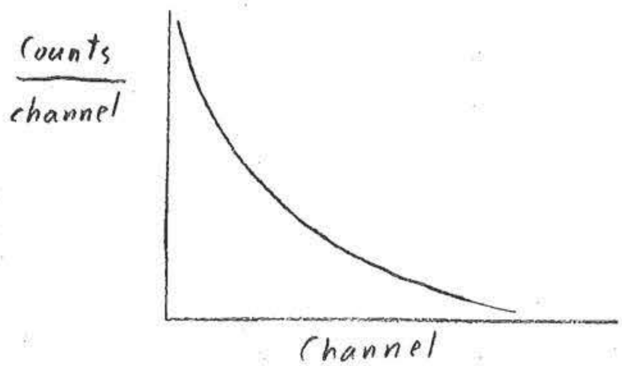


Fig. 19

Noise Spectrum

The muon peak isn't observed since muon events occur infrequently (there are $9 \times 10^{-3} \frac{\text{muons}}{\text{cm}^2\text{sec ster}}$ with energies above 140 Mev) at sea level.

In order to diminish the noise portion of the curve, coincidence with another counter can be required before the analyzer accepts pulses.

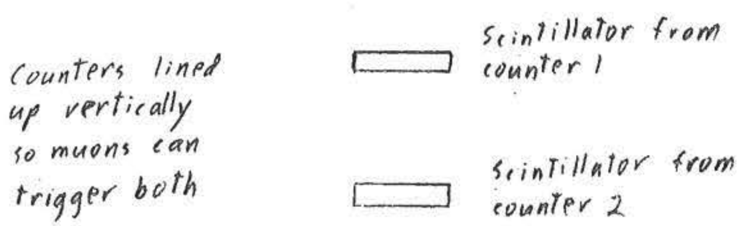


Fig. 20

With the second anode 50 Ω terminated, a Compton edge of Co^{60} of 500 mv will be obtained for an operating voltage somewhere between 1700 v and 2100 v. The spectrum from the analyzer will now look like Figure 21.

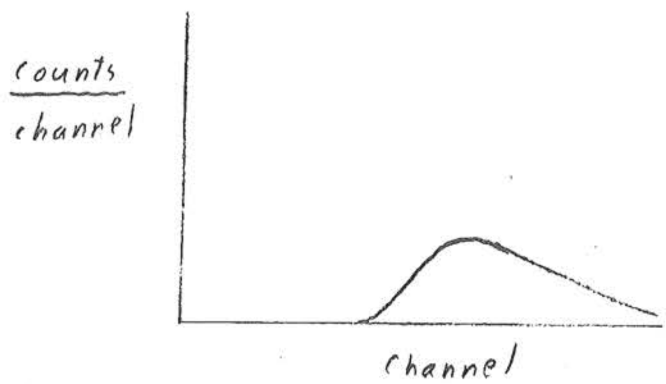


Fig. 21

If the tubes are operated at too high a voltage, the spectrum will contain accidental noise coincidences and will now look like Fig. 22.

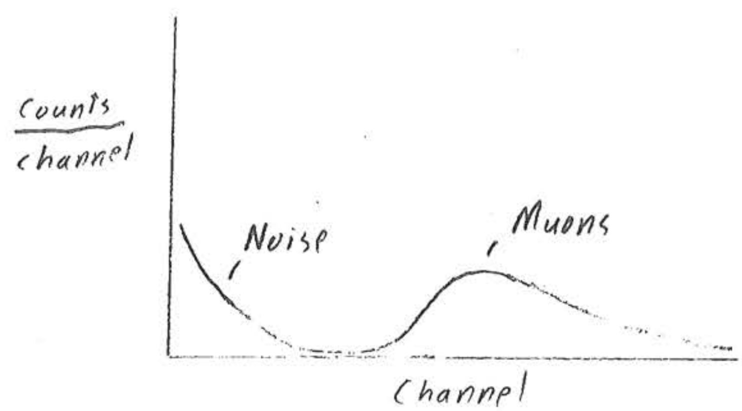


Fig. 22

Most muons are relativistic and approximately minimum ionizing. There are several effects which broaden the muon spectrum. The most important is the statistical fluctuations in energy loss of the muons due to collisions with

with electrons in the scintillator. For thin absorbers, such as the 1/4" scintillators, the energy loss has the form of a Landau distribution.[2]

DETERMINING COUNTER VOLTAGES

If the count rate for a counter triggering a discriminator is obtained with a scaler as a function of voltage (no radioactive source placed nearby) the result will be an integral spectrum, as shown in Figure 23.

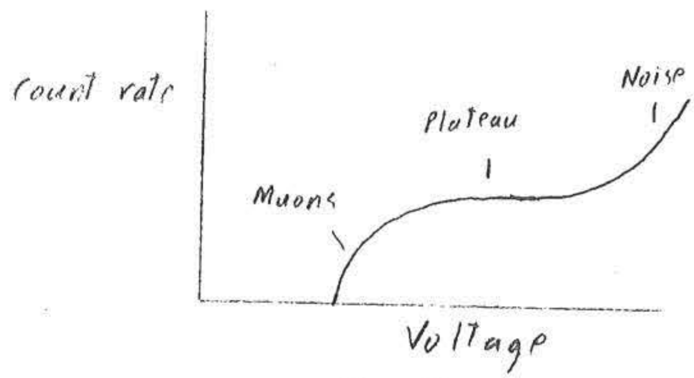


Fig. 23

(A second counter with fixed voltage is in coincidence.) (Increasing the voltage is equivalent to decreasing the discriminator threshold.) The voltage on the counter should be such that it is operating in the plateau region.

To set the voltage on the counter, the output must be observed on the oscilloscope. Muons can't be used to set the counter voltage since they occur so infrequently. The Compton edge of γ-rays from a Co^{60} source is approximately the same as the energy loss of a minumum ionizing electron in a 1/4" scintillator of NE 102. The maximum energy a photon from Co^{60} can lose in a collision with an electron is 1.1 Mev. The mean energy loss of a minimum ionizing muon in 1/4" of NE 102 is 1.3 Mev. Fewer than 1% of all muons lose an energy less than 0.7 Mev. [3] The Compton edge of the

Co^{60} can therefore be used to set the counter voltage.

I adjusted the voltage of the counters to an output of 500 mv for the Co^{60} Compton edge. The discriminator was set at 200 mv.

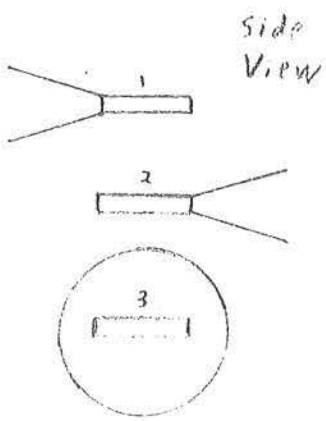
CERENKOV RADIATION

A charged particle can pass through the light pipe and emit Cerenkov radiation. The muon counter can therefore trigger the discriminator even though a charged particle didn't pass through the scintillator. This problem of Cerenkov radiation, which has been ignored so far, will now be discussed.

When a charged particle has a velocity exceeding the speed of light in a dielectric material, it radiates photons. The energy loss per path length from Cerenkov radiation is [4]

$$\frac{dT}{dx} = \frac{4\pi^2 z^2 e^2}{c^2} \int \left(1 - \frac{1}{\beta^2 n^2(\nu)}\right) \nu \, d\nu$$

where $n(\nu)$ is the index of refraction, ν is the frequency, $B = \frac{v}{c}$, and ze is the charge on the moving particle. $\frac{d\tau}{dx}$ is of the order of 1000 $\frac{ev}{cm}$ between 3500 A and 5600 A (50% maximum response for an S-11 Photocathode) for a relativistic ($B \sim 1$) muon in lucite ($n \sim 1.5$). The larger length and thickness of the muon counter's lucite light pipe compared to the scintillator increases the relative geometrical factor of the light pipe and increase the relative energy loss due to Cerenkov radiation. The 2 1/2% conversion efficiency of ionization energy loss to light for NE 102 decreases the relative light output due to ionization losses. The light energy produced by Cerenkov radiation is still less than that produced by a minimum ionizing particle passing through the scintillator. However, if the discriminator is set too low, or if a muon passes through the length of a light pipe, Cerenkov radiation may trigger the coincidence circuit. The light pipes should be arranged in a way to minimize the possibility of a coincidence due to Cerenkov radiation.



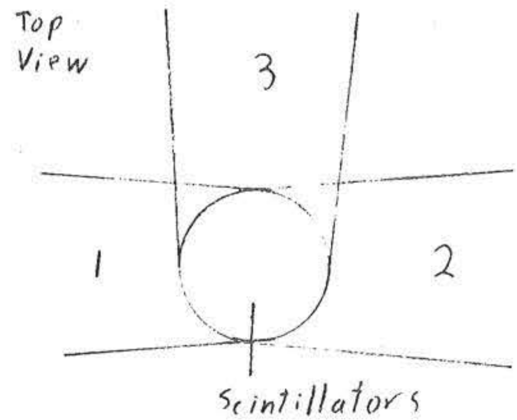


Fig. 24

A possible configuration is shown in figure 24.

SHOWERS

The possibility of a radiation shower producing coincident events in the muon telescope should be mentioned. A high energy electron can produce an electromagnetic shower consisting of γ-rays, positrons, and electrons. If this shower orginates in the ceiling there is a finite probability that more than one particle will trigger the muon counters within the resolving time of the electronics. These coincidences may look like a particle with an abnormally high $\frac{dE}{dx}$ (see figure 25). The possibility of coincidences due to showers can be mimized by using as an anticoincidence a large muon counter situated horizontally with respect to the muon telescope as in Figure 25.

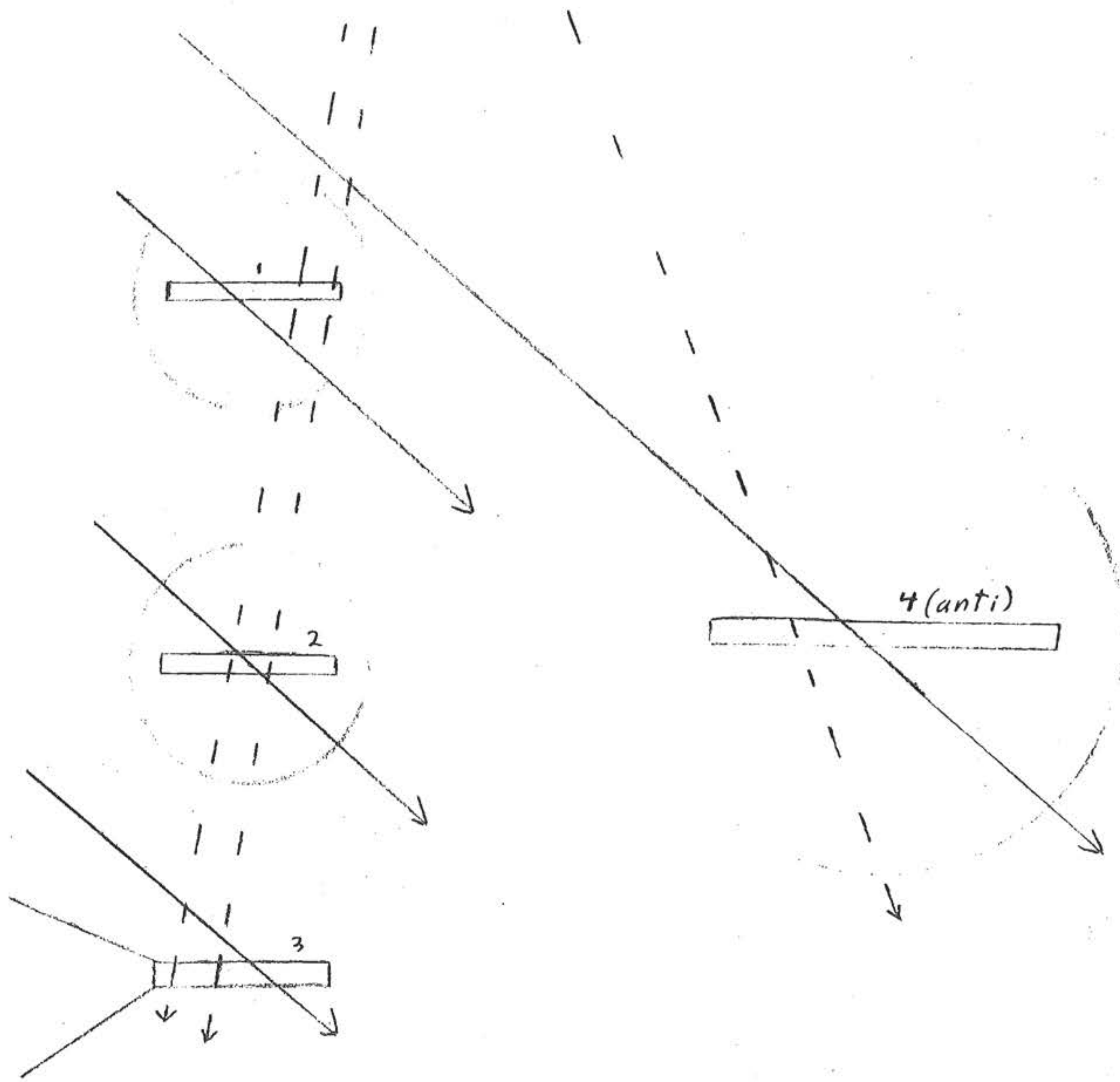


Fig. 25 Require 1 2 3 $\overline{4}$

⟶ Indicate particles from 2
- - → different showers

DETERMINING VOLTAGE FOR IMP PHOTOTUBE

The set up is shown in Figure 1. The muon counters should be arranged to minimize the possibility of a coincidence due to Cerenkov radiation from the light pipes. The voltages on the muon counters are determined by the method described previously.

The spectrum seen by the phototube looking at the scintillator cup goes through the charge sensitive amplifier and is recorded by the pulse height analyzer. The pulser is used to convert the channel spectrum in the analyzer to a charge spectrum. The calibration input of the amplifier (from the pulsar) has a 220 pf capacitor. The charge deposited is therefore

$$Q = VC$$

where $C = 220 \times 10^{-12}$

V = voltage of pulse

This charge corresponds to the channel of the analyzer into which the pulse falls. The voltage of the photomultiplier tube can be adjusted until some fraction, say 99%, of the muons lie above the 1.4 pc threshold of the IMP anticoincidence cup discriminator.

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3. Calculated from formulas in Rossi's book.

4. Robley D. Evans; The Atomic Nucleus; chap. 18, 21; McGraw-Hill Book Co.; New York, 1955.