SOME ADDITIONAL NOTES FOR MUON LIFETIME EXPERIMENT

EXPERIMENAL PROCEDURES

ADDITIONAL NOTES ON MUON LIFETIME EXPERIMENTAL PROCEDURES

(1) Set the best EHT voltage for the system

... Make sure the EHT supply power is on, and power is on to the Scintillator unit, with the PM signal going to the "PM Input" of the PM Adaptor unit

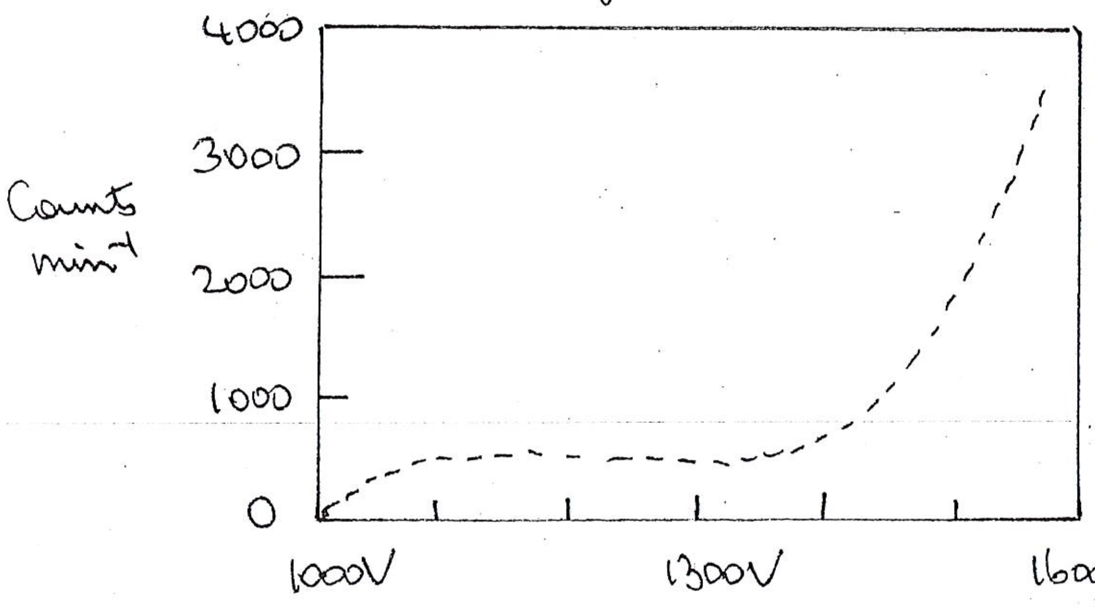
... Take the "PULSE" output of the discriminator on the PM Adaptor unit into the input of the Physics Counter-Timer

... Try a range of EHT values and plot counts per minute versus voltage [Note: Do NOT exceed 1800V.]

... Check the V_{REF} is ~ −0.5V before doing this

? .5V

Plot typically is as below:

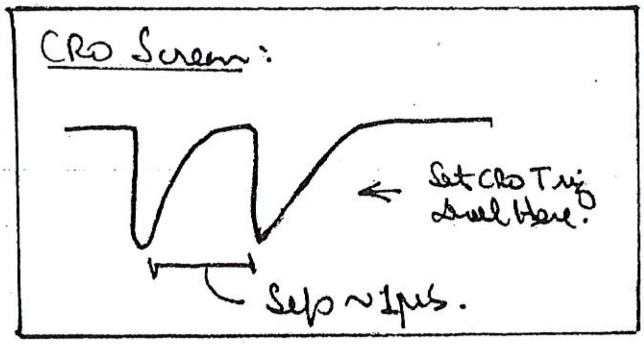


... a reasonable choice of EHT from this plot would be ~1300 V. Once chosen and set, do not alter the EHT for the rest of the experiment

(2) <u>Calibrate the time seperation of pulses versus bin number on the PHA</u>

... Firstly set up the tail-pulse generator unit to give suitable pulse pairs, say ~ 1 μs apart initially. These may be seen directly on the digital CRO screen, and their <u>time seperation</u> ** measured. Vary the "DELAY" and watch the pulse seperation change.

Example settings: Freq. ~100 Hz
Double Pulse
Rise Time ~ 0.2μs
Fall Time ~ 0.5μs
Delay ~ 1μs
Reference = Internal
Polarity = Negative
Attenuators = Off
Voltage Amplitude ~ -1V



... Perhaps use a Tee-junction to have the signal going to the CRO, but also take it to the "PM Input" of the PM Adapter Unit.

** <u>Note</u>: The accuracy of the CRO timebase will ultimately limit the systematic errors present in your muon lifetime measurement. This would have to be carefully checked

... Connect up the out puts of the PM adaptor unit to the two channels of the CRO and confirm the double-pulse seperation time is seen between the two out puts.

i.e. { START → CH 1 of CRO
STOP → CH2 of CRO.

If this is <u>not</u> the case, and you instead see the double-pulse repetition time, then the electronics is "starting" on the second of a pulse pair, and "stopping" on the first pulse of the next pair. If this happens flick the pulse generator on and off a few times, until you eventually get it triggering the PH PM Adaptor unit in the correct manner.

... Now connect the outputs of the PM Adaptor Unit to the inputs of the THC.

i.e. { PM Adaptor START → THC START
" " STOP → THC STOP

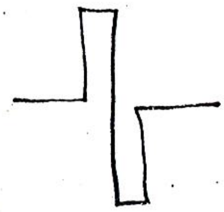
... Take the out put of the THC, (the bottom L.H.S. "CONVERTOR" output) and look at it on the CRO. You should be able to see that the <u>amplitude</u> of these out put pulses varies as you alter the delay between pulses in a pair using the "DELAY"

Example suitable setting on THC:

Range ~ 10 μS
Amplitude* ~ 5V
full Range

(* Later when the PHA unit is added, you may find you want to increase this to 8V. It is the maximum voltage output pulse you get, corresponding to the maximum time interval on the "Range" setting)

On the CRO, the output of the THC is a bipolar pulse, thus

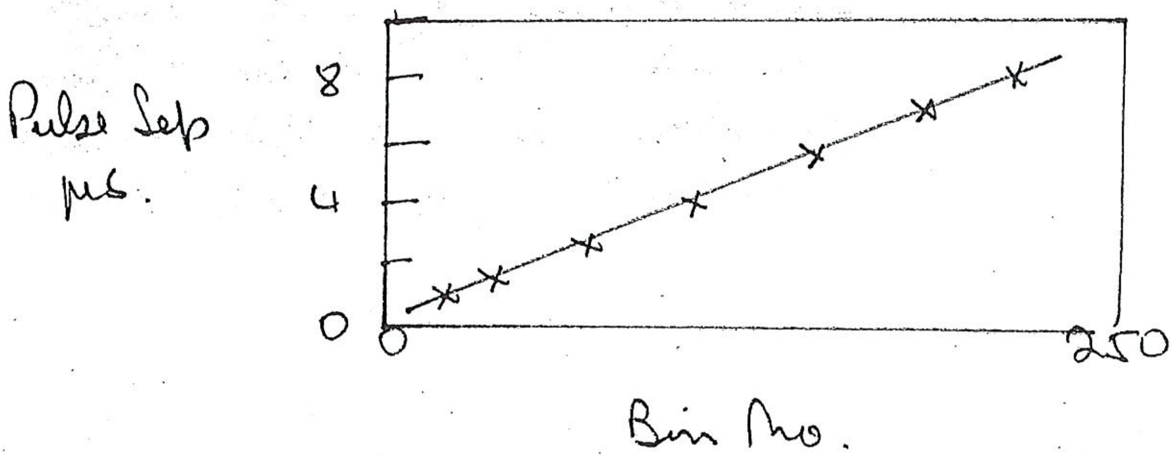


The total amplitude of this scales with the time interval between the two pulses in the pulse pair generated by the tail-pulse generator.

... now take the output of the THC and connect it to the input of the PHC on the rear of the trolley-mounted computer. Get the PHA program going. You should find pulses accumulate in a single bin if you do not adjust the tail-pulse generator. This is because the THC is putting out fixed voltage (height) pulses for a given tail-pulse "DELAY"

... Now try varying the tail-pulse delay over much of the 0 – 10 μs range set on the THC, and see if the accumulation bin changes on the PHA screen in a linear fashion with time delay (it may have some small zero offset)

... Begin your calibration measurements if all is well. Record measured pulse-separation on the CRO and corresponding PHA bin number, for a range of times in the 0 – 10 μs duration. A linear-least-squares fit of the data, using for example EXCEL, will give the time versus Bin No. slope, and an error in this as well.



Note that linear-least-squares fits in EXCEL and most other routines assume no error on the X-axis measurement (here "Bin No") and

Pulse Separation)

Typical slope here is:

$$\frac{\partial t}{\partial \, \text{Bin No}} = 3.48\,(\pm 0.008) \times 10^{-8} \text{ sec}$$

$$\approx 3.5\,(\pm 0.01) \times 10^{-8} \text{ sec}$$

(i.e Fractional error ~ 0.2–0.3%)

[Shanahan + McCallum, 2001]

However, RECALL:
There may be a systematic error produced by a systematic error in the CRO time base, and this ultimately limits the accuracy.

... You may wish to use the internal calibration signal in the digital CRO to check the calibration of the CRO timebase, and then apply a systematic correction to your slope determination.

(3) Acquire Muon data

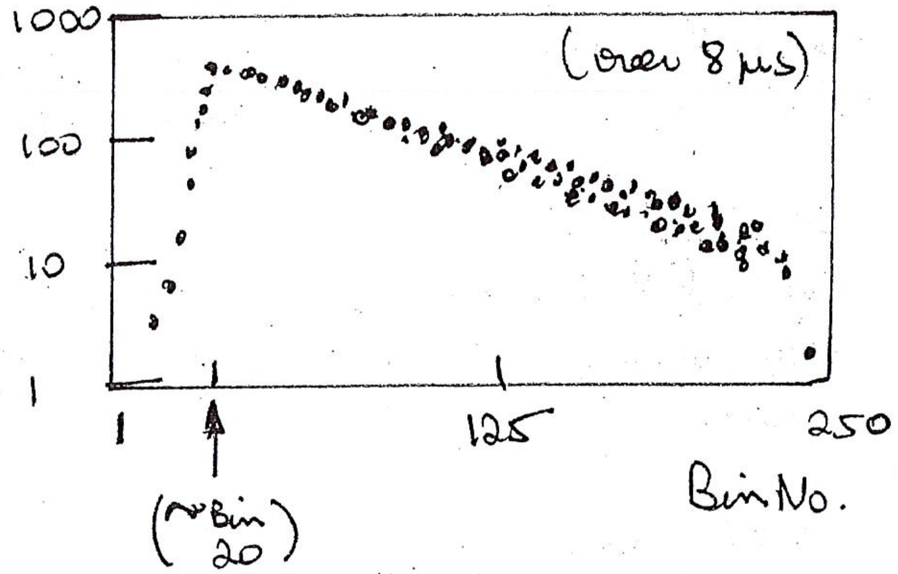
... Do not change any of your settings now that you have calibrated the system

... Un plug the tail-pulse generator from the PM Adapter unit and connect the signal from the PM tube in its place.

... Take the output of the THC and feed it into the rear of the Physics counter-timer to confirm that it gives a count rate of ~ 1–2 counts per minute expected from muons. You may want to place a Tee-junct-ion at the output of the THC and have both the grey Physics counter-timer and the PHA unit connected all the time as you accumulate data. You will probably need to acquire data for at least a week (or even a couple of weeks) to get good statistics.

e.g. In 2 weeks, with a count rate of 1–2 min^{-1} you will acquire ~ 10,000– 20,000 events spread over, say, 256 PHA bins. This corresponds to only ~ 100 counts per bin.

Typical data (on a log plot):



[Shanahan & McCollum, 2001]
19 days counting 0 – 8 μs

... Typical data on a log plot will be linear. Background has to be removed before analysis can be undertaken (see next stage of experiment) There is a fall off in data at low bin numbers (here ≲ 20) due to the finite width of the pulses occuring ~~producing~~ overlap and so generating only one output pulse, and hence not being registered in our THC counting procedure.

The statistics at the large bin end is poorer, and the data shows a larger fractional scatter.

... Discard low bins, and any high end

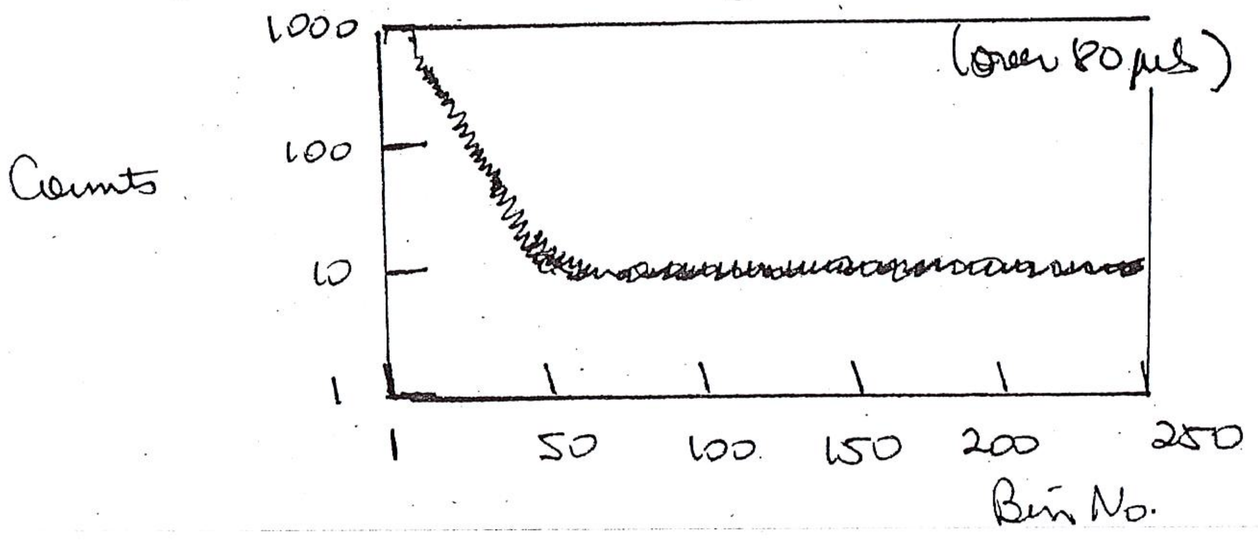
analysis of your data commences.

(4) Determine Background

... Now set the maximum time "RANGE" on the THC to a large value, say ~ 80 μs and accumulate again for a reasonable time, of say a week, to get adequate background statistics.

... The point here is that at large time delays (80 μs corresponds to ~ 50 muon half lives) all the counts are background. Hence the PHA screen will show counts falling with larger bin number up to some point, and then approximately constant with bin number above this point. This constant value is the background you wish to determine

Typical data (on a log plot):



[Shanahan + McCallum, 2001]
7 days counting 0–80 μs

In this typical data we see a merging of count lots into a background at about bin 50. In this data bin 50 corresponds to a pulse seperation of ~25μs, so we have

{ BIN 80 (~25μs separation)
→ ~15 half lives

BIN 250 (~80μs separation)
→ ~50 half lives

($\tau_{\frac{1}{2}} \sim 1.5$ μs for muons)

Hence the range from say bin 70 to bin 250 should be pretty well uncontaminated with muon data and if the average value (together with its uncertainty) is obtained from this part of a data plot, the background has been obtained.

... Be careful however in applying the background correction. You have to scale the background you read from this data plot to be consistent with your muon data plot.

→ Scale the background to account for the different total time of accumulat-ion here compared to the time over which you accumulated the muon data

→ Scale the background here (it is COUNTS PER PHA bin!) to allow bins are much wider than for your original muon data.

eg. { 256 bins here are over 0 – 80 μs whereas they may have only been over 0 – 8 μs in the original muon data

... Subtract your (scaled) background from your muon data.

eg. { for 2 weeks muon data accumulation you may be subtracting off ~ ~3 counts per bin. ~~At the~~ high-bin end, this may be reducing your muon data from ~ 10 counts per bin to ~ 7 counts per bin.

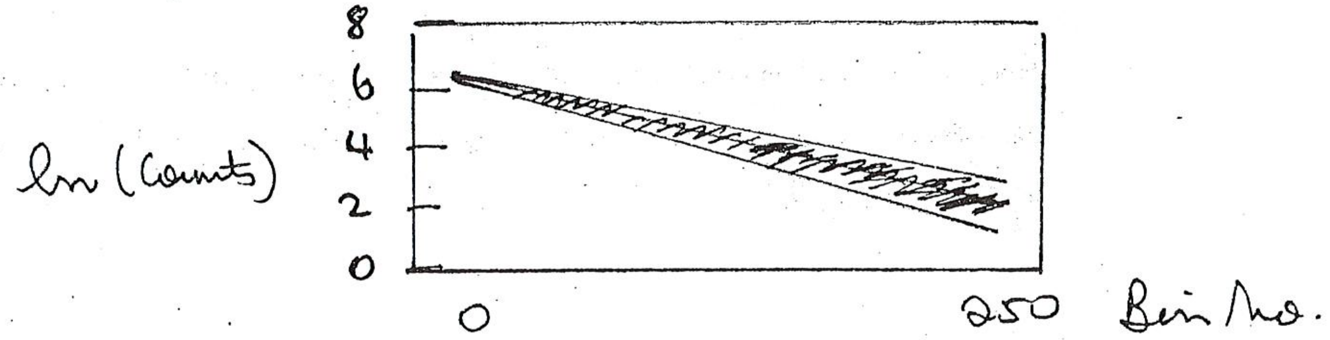
(5) Undertaker Analysis

... On a logarithmic plot show

ln (Counts) versus Bin No.

(Background corrected)

Typical Data:



... Use, say, EXCEL to give a linear regression, and determine the slope and uncertainty in the slope. Again this assumes all uncertainty is in the Y axis measurements, and none along the X axis (Bin Nos.)

Typical slope here is:

$$\frac{\partial \ln[\Delta N]}{\partial \text{Bin No}} = 0.0165 \pm 0.002$$

[McCollum, 2001]

... Combine this with your calibration result to give

$$\lambda = \frac{1}{t_{AV}} = \frac{d}{dt}\left[\ln_e(\Delta N)\right]$$

↑ Slope

$$= \frac{\partial\left[\ln_e(\Delta N)\right]}{\partial\,(\text{Bin Number})} \times \frac{\partial\,(\text{Bin Number})}{\partial t}$$

The uncertainties of the two slopes have to be combined to give you the total uncertainty of the result.

... Hence a typical calculation would be

$$\lambda = 1/t_{AV} \sim 0.0165 \times \frac{1}{3.48 \times 10^{-8}}$$

$$\sim 474{,}000 \pm 5000 \ \text{sec}^{-1}$$

Thus $t_{AV} \sim 2.1 \pm 0.1 \ \mu s$.

[McCollum, 2001]

Here the error comes from the square root of the sum of the squares of the fractional uncertainty in each of the two terms giving the fractional

SOME ADDITIONAL NOTES FOR MUON LIFETIME EXPERIMENT

EXPERIMENAL EQUIPMENT

ADDITIONAL NOTES ON MUON LIFETIME EXPERIMENTAL EQUIPMENT

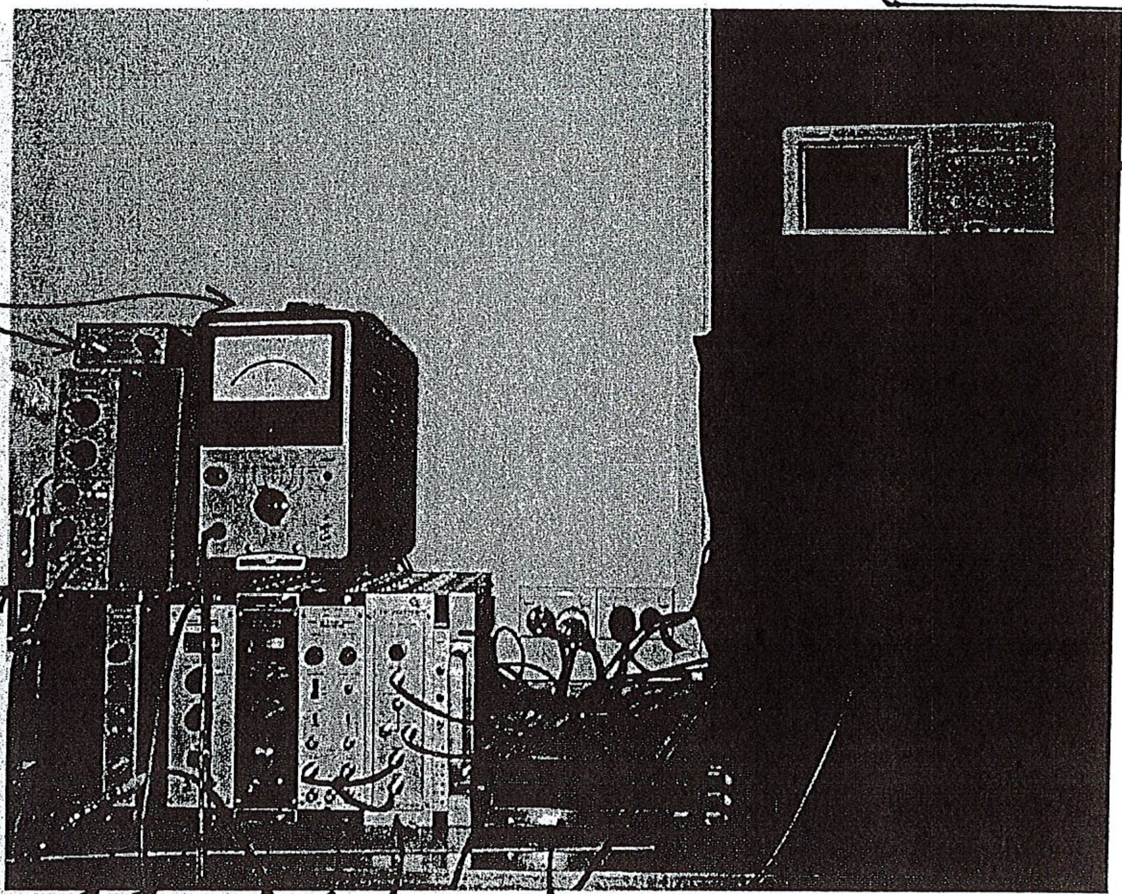
The following pages contain

... image of equipment, pointing out those electronic items used in the muon lifetime experiment and those items that are <u>not</u> used in this experiment.

... close-up images and detailed sketches of the items that we do need

THIS EQUIPMENT IS NOT USED IN MUON LIFETIME EXPERIMENT

Digital double-beam oscilloscope



Counter-Timer

P.M. Tube and Scintillator Unit

BNC Tail Pulse Generator (to generate double pulses for calibrating the experiment)

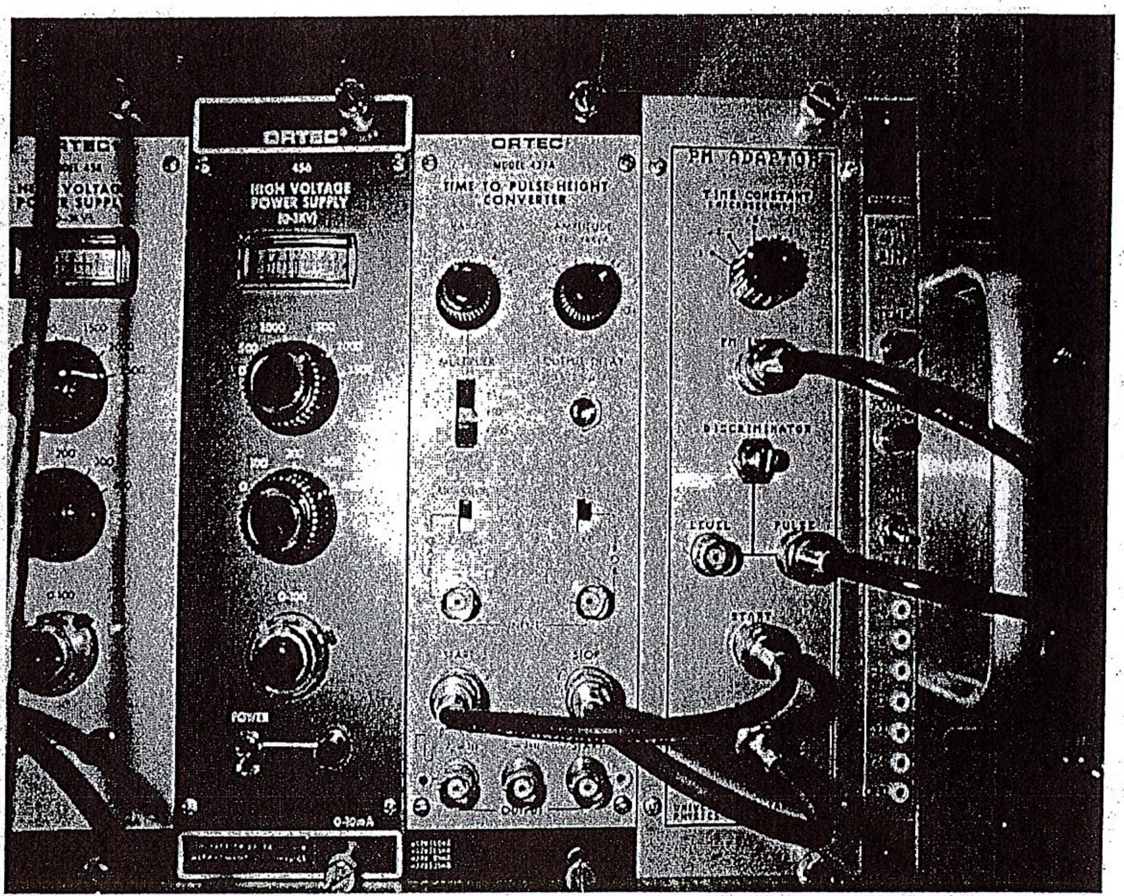
P.M. Tube Adaptor unit

Ortec Model 437A Time to Pulse Height Converter [THC]

[PHA] The required Pulse-Height Analyser unit is a card mounted in a dedicated P.C. and this P.C. is set on a movable trolley. It is not shown in

Ortec Model 456 High voltage Power Supply

CLOSE-UP OF RACK-MOUNTED UNITS



EHT Unit — THC Unit — PM Adaptor Unit — Rack Power Supply Unit

The 240 V to rack-mounted units requires, in some cases, that the <u>rack power supply</u> (the R.H.S. narrow unit) be <u>turned on</u>. The THC and PM Adaptor units get their power via the rack, for example. Some other units are simply plugged directly in to a wall socket for 240 V.

PM Tube Plus Scintillator Unit.

... P.M. Tube & scintillator is inside metal box (you can look inside when power is off)

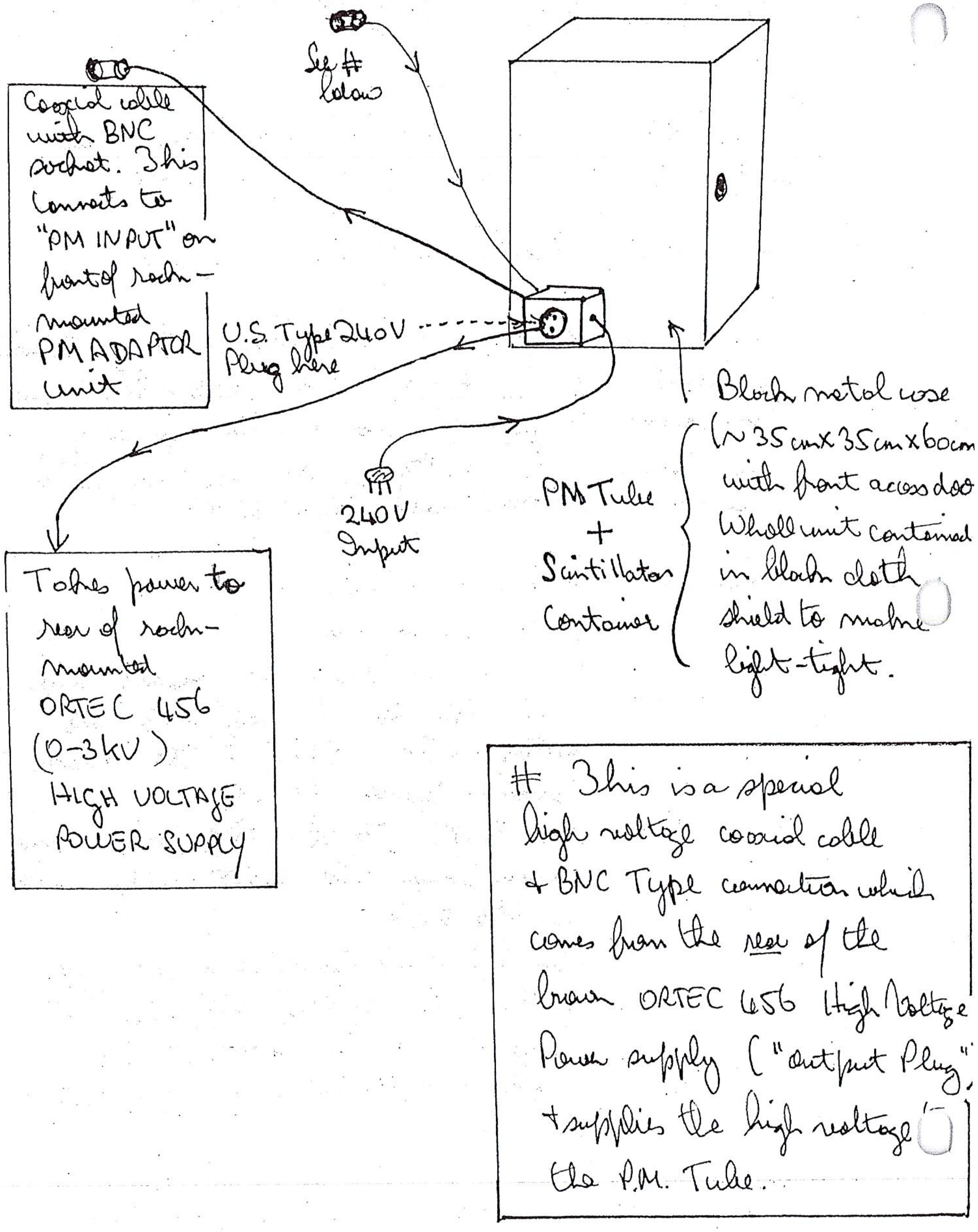
... Cover with black cloth when in use.

... When counting you should keep the outside window blinds down and preferably also the room light off to minimize any scattered light entering the system (if the room is not being used by others)

... Required connections are —
- 240 V in to unit
- the mains power is passed (via a U.S. style 240 V plug) to the Ortec ~~456~~ 456 EHT in the rack to provide power to it
- the EHT to the PM tube comes back from the Ortec 456 unit in the rack
- the P.M. output signal goes out and connects to the "PM Input" on the front of the rack-mounted PM Adaptor unit.

... The output pulses from the PM tube are negative voltage pulses.

PM Tube plus Scintillator Unit



PM Adaptor Unit

... P.M. Adaptor unit is powered up by the rack power switch being on.

... The "time constant" knob controls the width of the pulses that are sent on to the THC unit. They should be as narrow as possible, so set this to 0.1 μS and leave it there

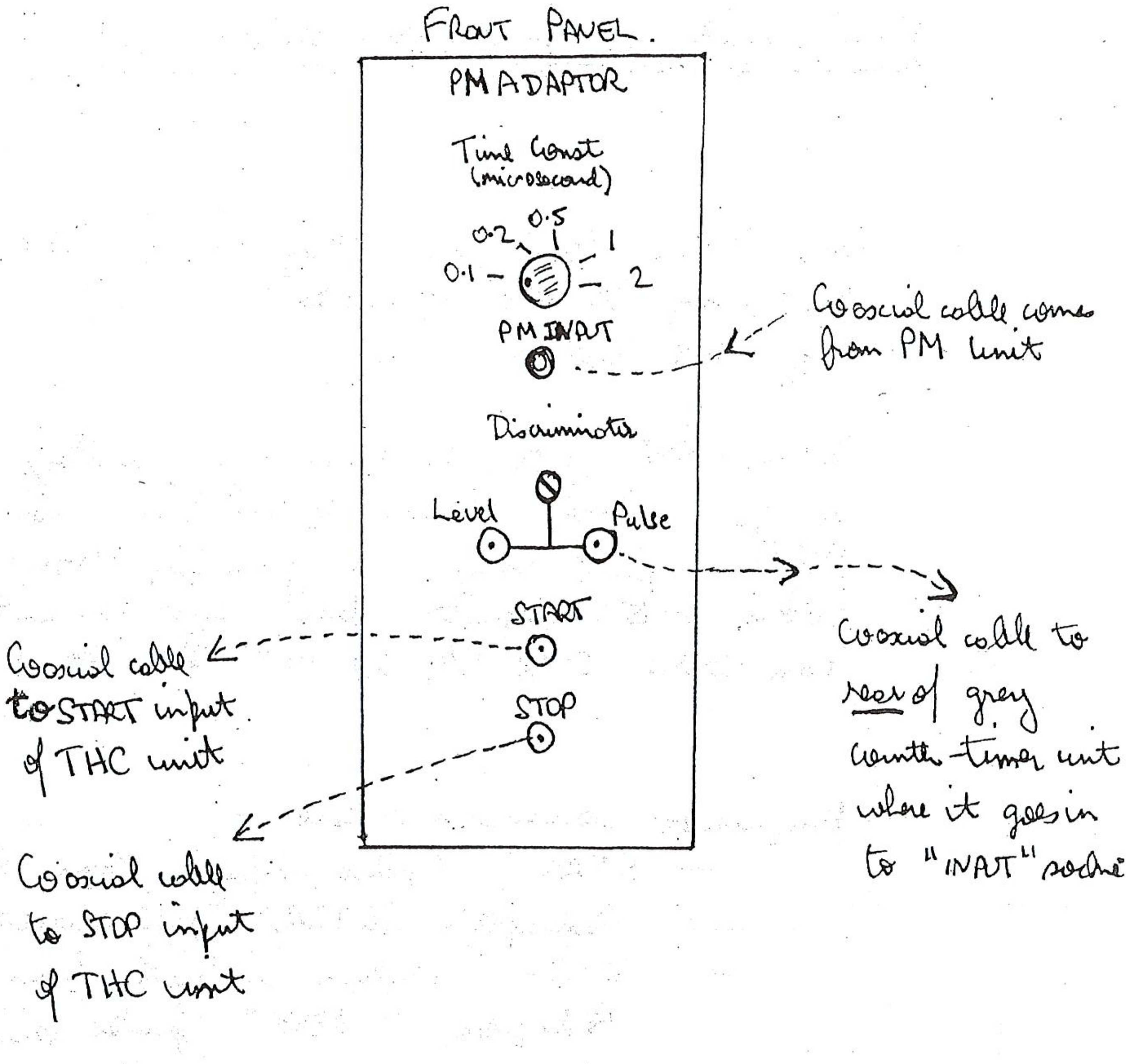
... The discriminator "Level" can be checked and should be set to −0.5 V on a CRO or multimeter.

... Required connections are —

- coaxial cable from PM tube to "PM Input" bringing the pulses into the adaptor from the PM tube
- coaxial cables out with
  - START going to START input on THC unit
  - STOP going to STOP input on THC unit
- coaxial cable from Discriminator "Pulse" output to the rear input "INPUT" socket on the grey Physics - Department counter-timer

This permits the total number of PM pulses, above the discriminator level, to be counted by the counter-timer.

PM Adaptor Unit



There are no connections on the rear panel of this PM adaptor unit.

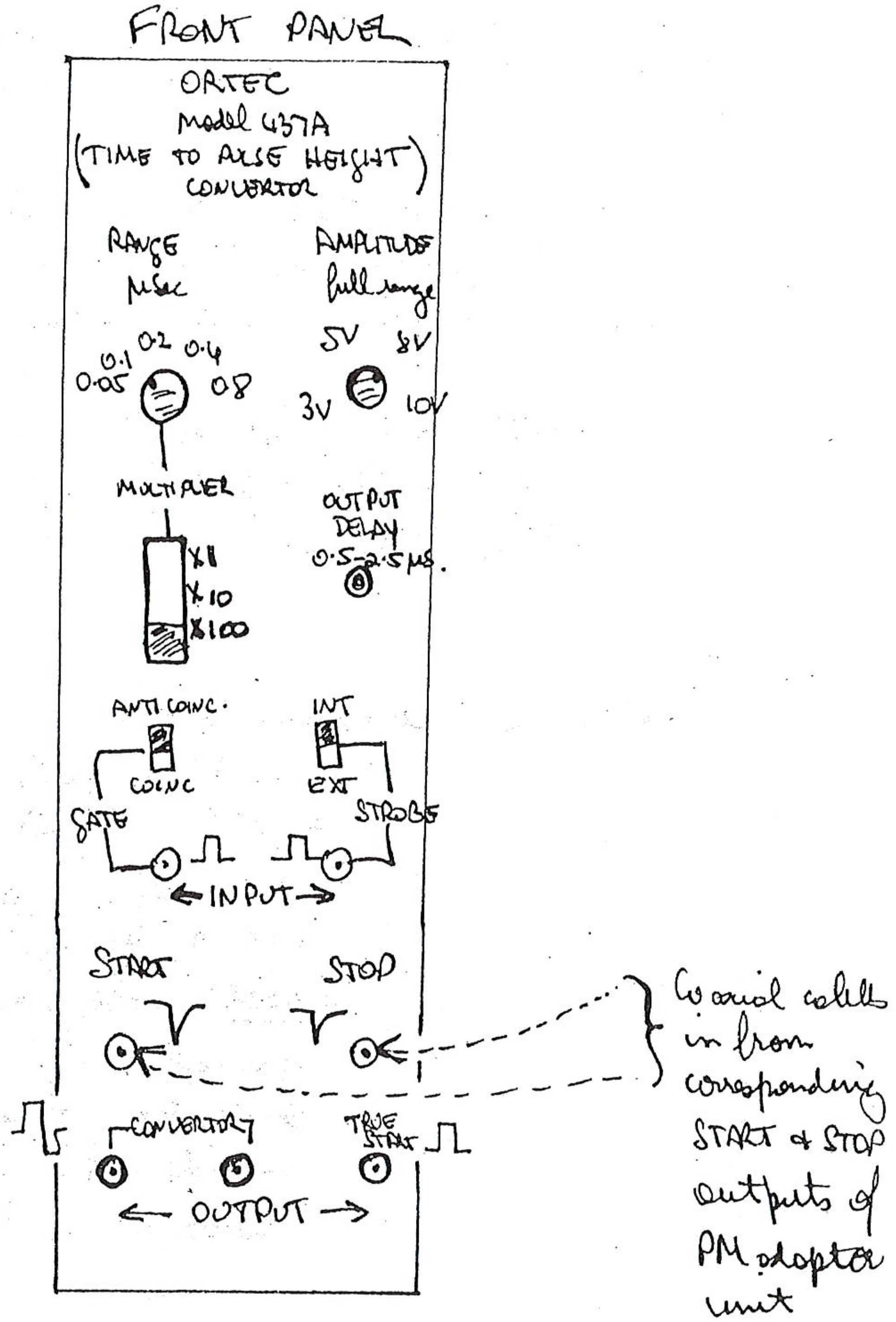
THC Unit (Time-to-pulse-height-converter)

... "Range" and "multiplier" together fix the time range to be converted.
eg 0.8 X10 = 8 μs

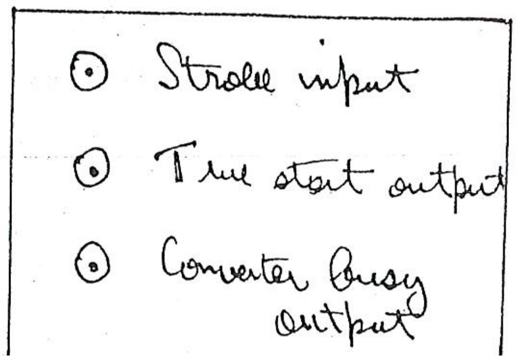
... AMPLITUDE sets the maximum voltage output range, which should equal the maximum PHA input range. Typically PHA's can take 0-5V inputs, but our current one can take 0-8 V, so set this to 8V

... Required connections are –
- START takes input from PM Adaptor "START" pulse output
- STOP takes input from PM Adaptor "STOP" pulse output.
- Take the output from the THC unit via coaxial cable on the L.H.S Converter output socket to the PHA unit. (The PHA unit is mounted in a dedicated P.C. on a trolley. The input socket to the PHA is marked on the rear of the P.C.)

THC Unit (Time to Pulse Height Converter)



Rear Panel of this THC unit has the following layout, but no connections are used in the execution of this experiment



EHT Unit (High Voltage Power Supply)

... This has a power on switch on the front. Don't forget to turn this on. Power comes from a 240V wall socket.

... Coarse and fine voltage settings are on the front. Do <u>NOT</u> exceed 1800V applied to the PM tube.

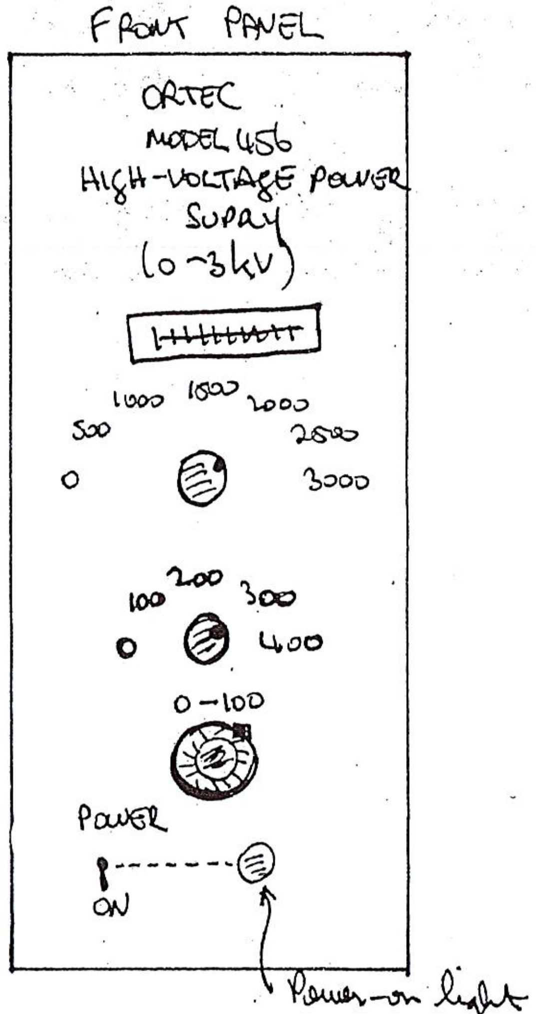
... Required connections are –
- 240V input at rear
- EHT output from "OUTPUT" rear via coaxial cable to PM tube and scintillator unit
  (<u>Note</u>: The connection here is a special EHT version of a BNC connector, that does not allow accidental use of a low voltage coaxial cable in the socket)

<u>Note</u>: The electronics rack has two EHT units, side by side. We only need one of these for this muon lifetime experiment. The only difference between the two is that one (the silver-faced one) is powered through a normal Australian 240V plug and socket, while the other one (the brown-faced one) has an American-type 240V plug and so must [illegible]

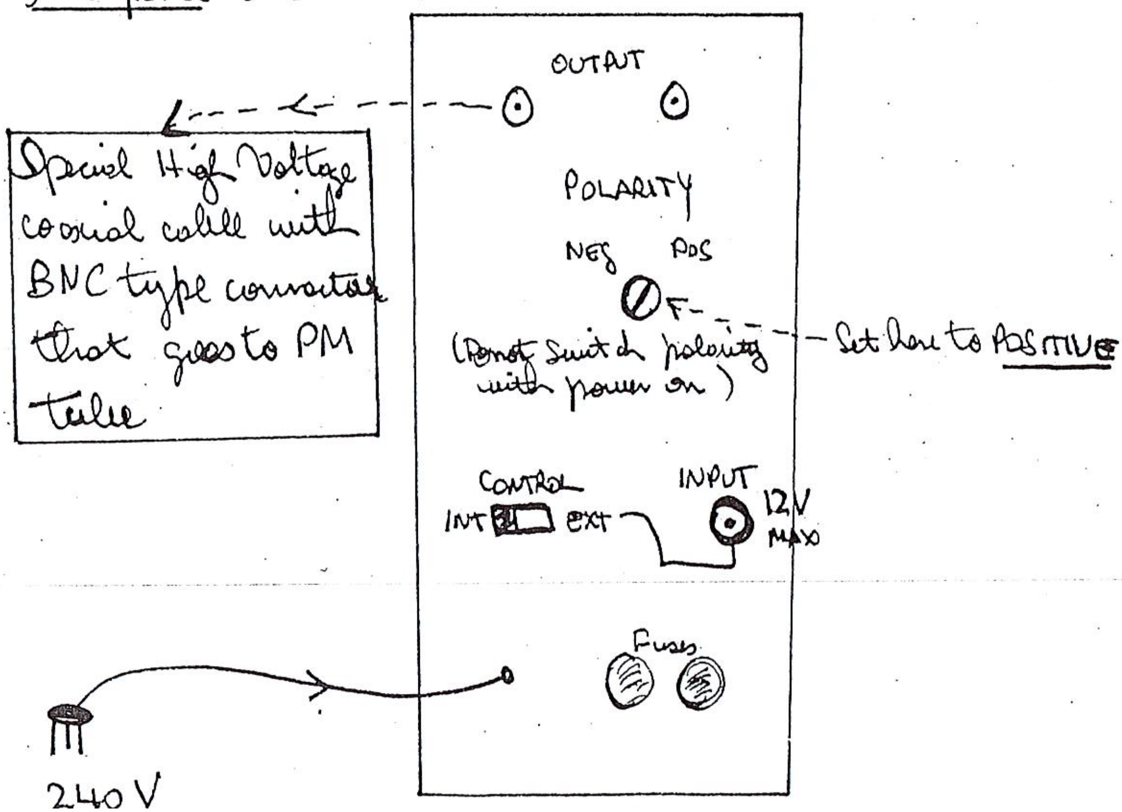
the side of the "PM tube plus scintillator" unit which has the appropriate American socket

Currently the experiment is set up to use the brown-faced EHT supply

High Voltage Power Supplies



There are no front panel connections, but there are rear panel ones thus:



BNC Tail-Pulse Generator

... This is a stand-alone unit, not mounted in the main electronics rack, and is used to generate a series of double-pulses in the process of doing a calibration of the bin number versus pulse seperation on the PHA unit.

... Required connections –
- 240 V to rear from a wall socket
- Coaxial cable from "PULSE OUT" socket on front to the input socket of the "PM Adapter Unit" when you are using these pulses to calibrate your system. Alternately take the coaxial cable to the CRO to examine output pulses

Functions and Settings on the Tail-Pulse Unit:

... Frequency function:
This determines the time interval between single pulses, or the time interval between one pulse pair and a second pulse pair.

e.g. {A low value, ~ 100 Hz is suitable
{for us for testing

... Toggle to "DOUBLE PULSE" for our

... Rise and Fall times:
Set these very short,
e.g. Rise time ~ 0.2 μs
Fall time ~ 0.5 μs

... The "DELAY" quantity is the time "separation" of two pulses in a pulse pair.
Try a value of ~ 1 μs in initially getting the tail pulse generator going and checking your understanding of the equipment. When you get to the point of doing your calibration you will need to vary it over a range up to ~ 10 μs.

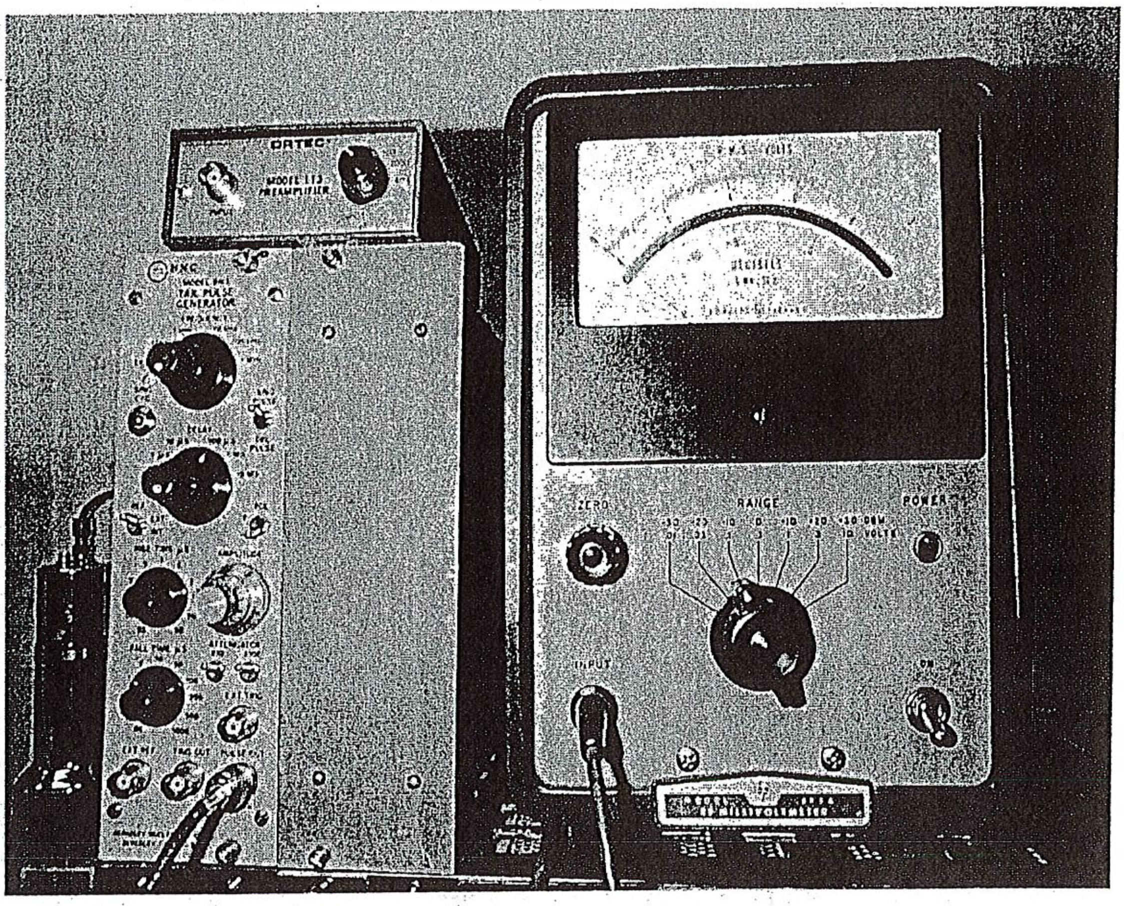
... "Reference" should be kept toggled to "INT". It is only used on "EXT" if the occurrence of the first pulse is to be triggered externally

... "POLARITY" should be kept toggled to negative to be consistent with the negative voltage pulses produced by the PM tube itself.

... "ATTENUATOR" settings should be off. Toggle these down to be off (I think!) and leave them there.

... "AMPLITUDE" should be set comfortably above the comparator threshold. For example, 2×(−0.5 V) ~ −1 V.

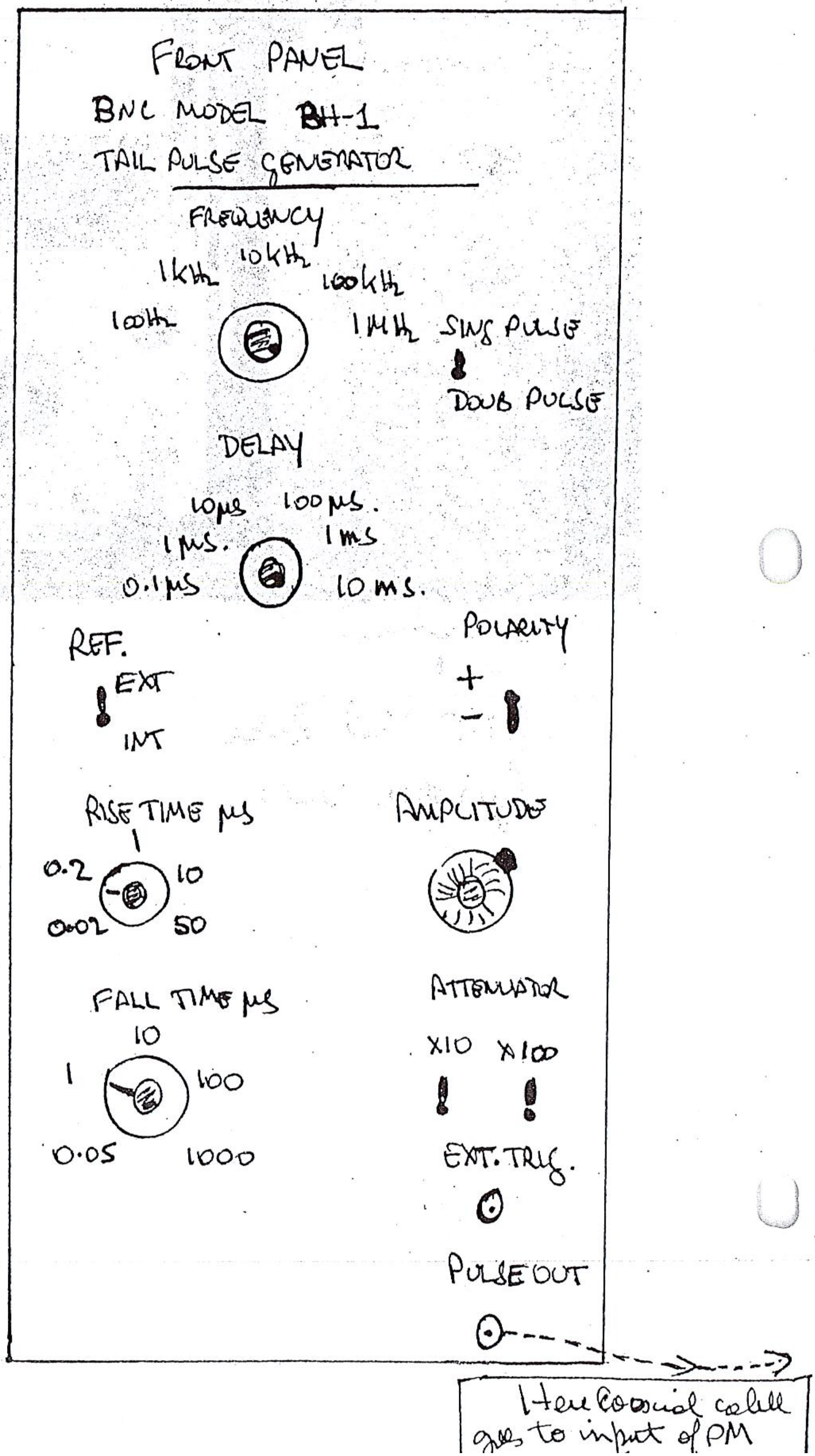
CLOSE-UP OF TAIL-PULSE GENERATOR



BNC Tail-Pulse
Generator Unit

BNC Tail-Pulse Generator

... This unit is the one that can provide double-pulses to calibrate the time-base in the experiment



Physics Counter-Timer Unit

... This is a simple counter timer with start, stop + latch facilities

... Required connections -

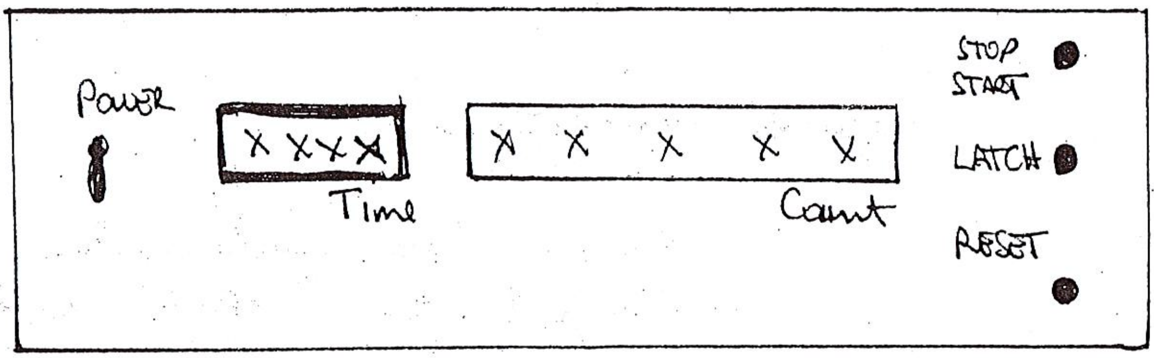
- 240 V from wall socket
- Input to "INPUT" socket on rear from, for example, the "PULSE" output socket of PM Adapter unit if you want to count PM tube pulses.

Standard Physics Department Counter-Timer:

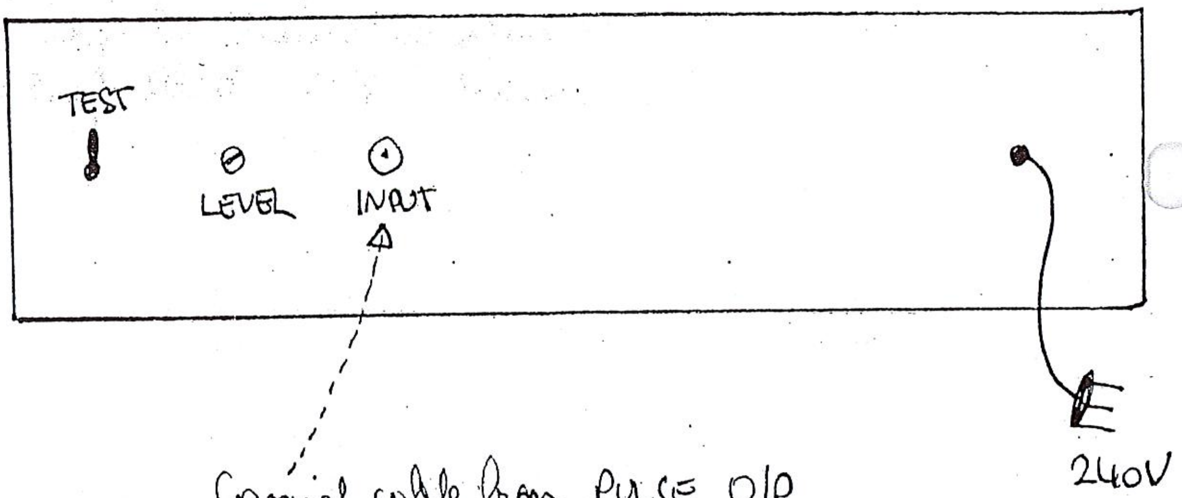
... This is a grey metal unit

~ 27W x 7 cm H x 20cm deep.

FRONT FACE



REAR FACE



Coaxial cable from PULSE O/P of PM Adaptor unit if you want to count PM tube pulses.

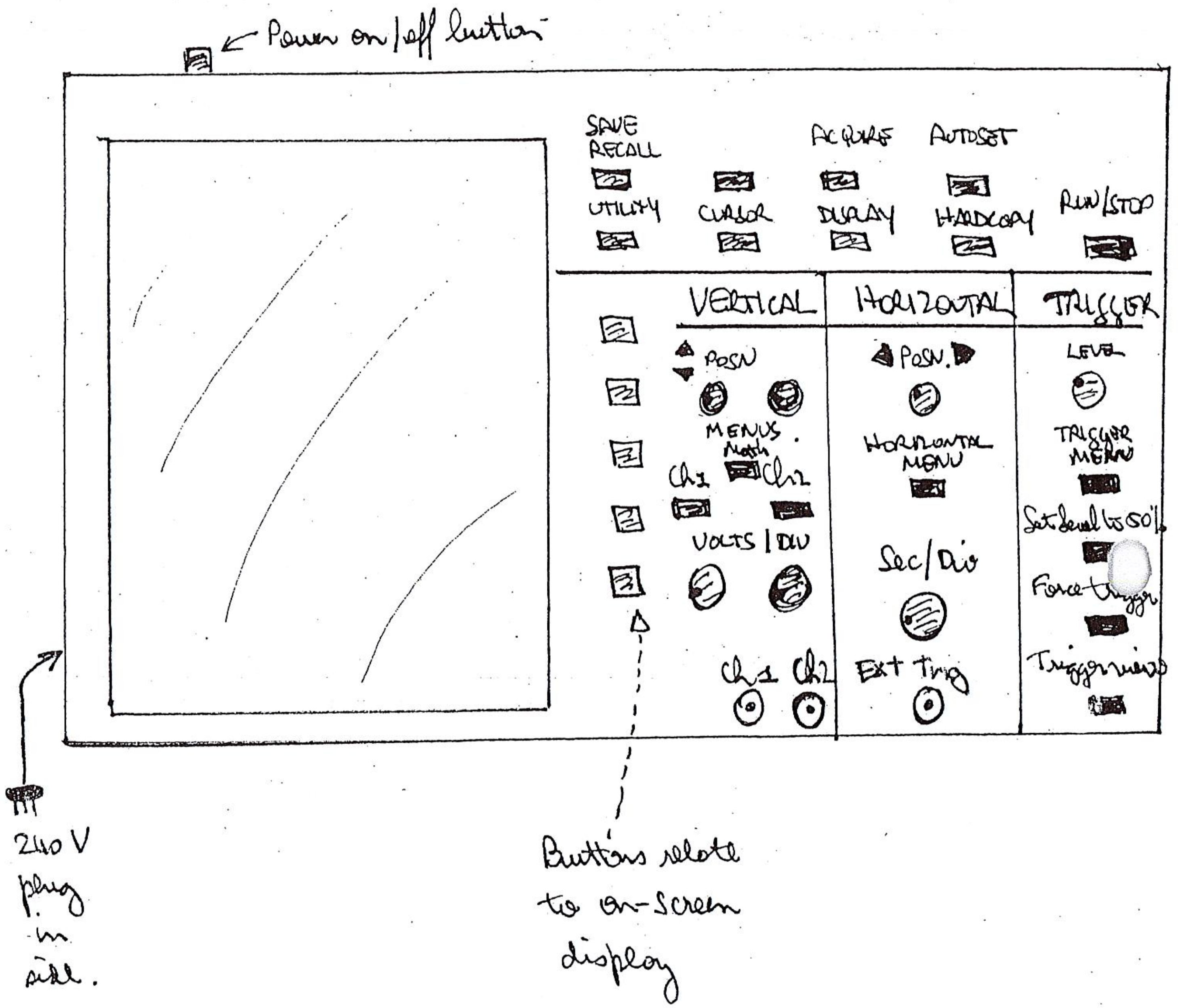
2-Channel Digital Tektronix CRO

... Standard digital CRO, with power on/off button on top

Standard 2-Channel DIGITAL Tektronix C.R.O.

(Model TDS 210)

FRONT FACE



PHA Unit (Pulse Height Analyser)

... This is a card built into a dedicated PC, and the PC is mounted on a wheeled trolley.

... Connect the output of the THC to the BNC "Input" socket of the PHA unit on the rear of the P.C. You can use a Tee junction on the output of the THC to view the pulses on a CRO at the same time if you want.

... The PHA unit requires positive pulses of about 5 V amplitude (the maximum it can deal with is ~ 8 V). It can also operate on the positive part of bipolar pulses, and hence will work on the pulses coming out of the THC.

... Turn on the Rainbow PC – its "Power On" switch is on the extreme right of its front face. The switch is styled like the case and is hard to see at first glance.

... The PHA program is run by going
C:> pha

... The PC has an attached dot matrix printer sitting on the shelf below the PC

The screen display of the P.H.A. program is as follows ...

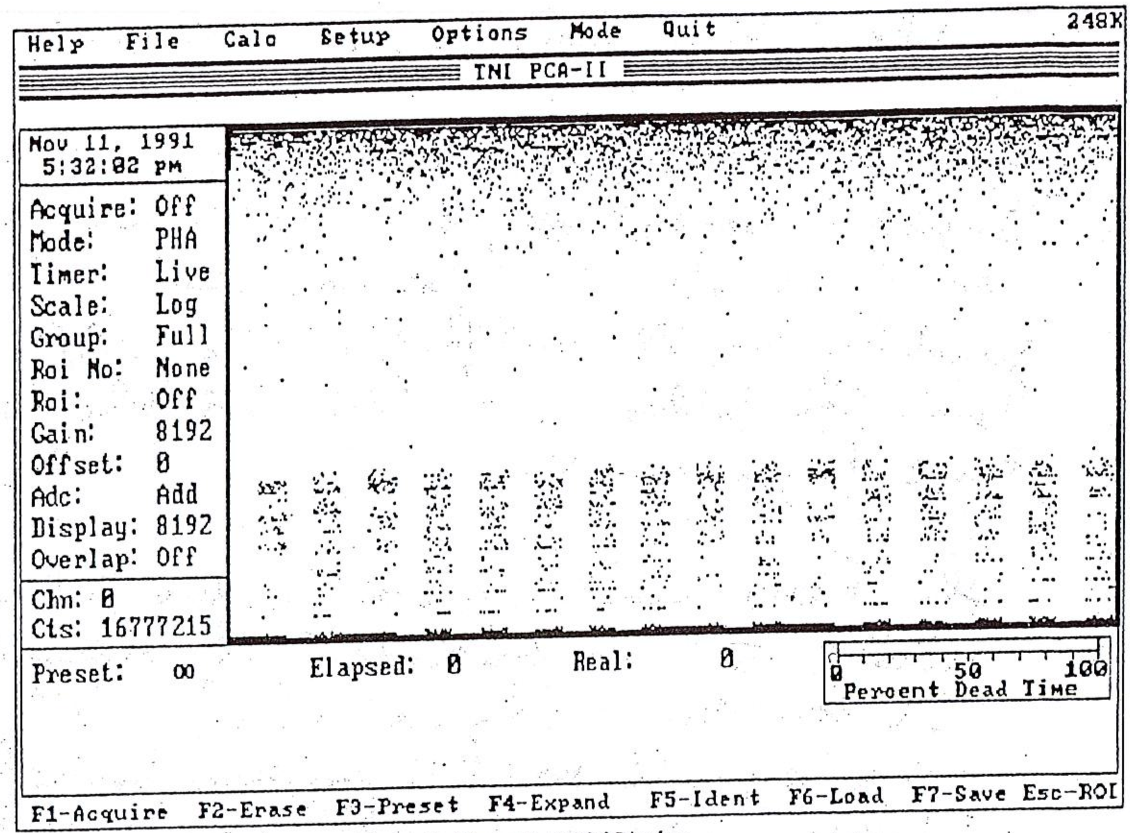


Figure 1. Initial Display

Operation of PHA Program:

(a) The "top-of-screen" menu items are accessed by "ALT + First Letter of Menu Item"

e.g. ALT + H = Help
ALT + F = File
ALT + Q = Quit

(b) The L.H.S. of screen gives a list of items indicating the current status of the screen display and program

(c) The "bottom-of-screen" function key list gives the main operational commands e.g.

F1 = Acquire ...
... Use this to start / Stop counting. When F1 is used to start the counting, the text next to "F1" is replaced by "Stop", and the "Acquire" item on the LHS of the screen goes from "Off" to "On". Toggling F1 again stops counting.

F2 = Erase ...

... This clears the screen and counter. As a safety precaution, hitting F2 alone does not do the erase, and merely makes the text next to "F2" become dim.

text to bright. To actually perform the erase action you have to type

"CTRL +F2"

(If the "F2" text is dim, this F2 key is not active, so you have to move to the bright text state for the "CTRL +F2" action to work)

F7 = Save ...

... This permits saving to a file. The file can then be transported to another PC for analyses or printing purposes.

(d) Printing of the screen directly is possible via the "FILE" menu item and its submenu item of "Graphics Screen Dump".

(e) The Y axis scale is shown as the "Scale" item on the LHS of the screen, and is accessed by the up-arrow and down-arrow keys. Pressing these keys gives a list of settings and then "ENTER" adopts the chosen setting.

Be careful, however, in that these up and down arrow keys change the setting by one place when they are initially used to display the setting menu.

(f) The screen cursor is accessed via the left-arrow and right-arrow keys. It can give you the ability of displaying the count in any selected bin.

(g) "ALT+Q" quits the PHA program.