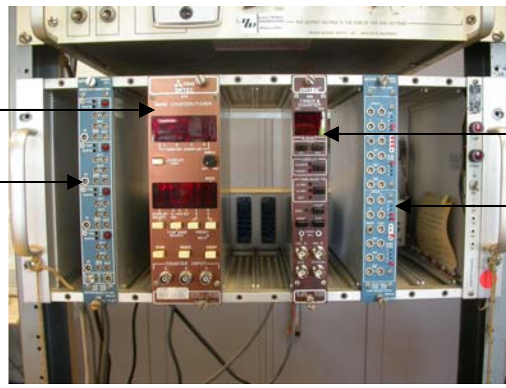
Time Measurement and Counting

1.0 Lab Apparatus

In this lab you will make use of a scintillating counter and the following NIM units: discriminator, coincidence and Counter/Timer units (see Figure 1).

Quad Counter/Timer

Discriminator



Single channel Counter/Timer

Coincidence unit

Figure 1

You will also use scintillation counters

Figure 2 - 2 in. by 3 in. scintillating plastic attached to "cookie" and PM and base

Figure 3 - Two PM's with a round flat piece of scintillating plastic mounted on the face of the PM's

In this experiment you will attach a piece of plastic scintillator to a photomultiplier tube (PM) to make a scintillation detector/counter, explore basic properties of scintillation counters, detect the two back-to-back gamma rays emitted by a ^{22}Na source and set up discriminator pulses to establish a coincidence between two scintillator detectors.

See W. R. Leo Ch. 9; also Knoll, Ch. 4 for information.

1.1 Assembling the Detector

The first task is to assemble a scintillation detector. (Read W.R. Leo section 9.6 for a step by step description of the process.) The material needed consists of the scintillator, in this case a 2 in. x 3 in. x ½ in. thick piece that has been bonded to a round plastic piece that looks like a cookie and is referred to as a "cookie", optical grease, aluminum foil, black construction paper and black electrical tape. The plastic cookie is mounted on the face of the photo tube using the optical grease that provides a good optical contact between the plastic cookie surface and the glass face of the photo multiplier tube.

Clean the surface of the tube with alcohol and wash the scintillating plastic with water if they are not already clean. (The Phys 433 support staff will provide a clean scintillator and tube.) The next step will be to wrap the plastic scintillator with aluminum foil that will reflect the light that exits the plastic scintillator. After which the photomultiplier tube (PM) surface is coated with optical grease and the cookie mounted on the tube. It is important that the optical grease covers the entire contact surface leaving no air gaps. Next make a light-tight enclosure using the black construction paper and tape, and mount the PM into one of the bases provided. The scintillator counter is complete and can now be used to observe and record signals!

Connect the anode output of a scintillation counter to the oscilloscope; terminate the cable at the scope. The pulses from the PM have a very fast rise and fall time and a very short duration, i.e. fast pulses. Consequently, the sweep speed of the oscilloscope should be about 100 ns per cm or less.

The high voltage input is connected (using a **high voltage cable**) to a power supply set for the polarity appropriate to the tube base you are using. Except for the muon lifetime detectors, all tube bases used in the Phys 433 lab require *positive* high voltage. Set up the oscilloscope to trigger on negative going pulses and cover the detector with a black cloth. This is done before applying High Voltage to the tube base.

Take a moment to become familiar with the switches and knobs on the power supply face plate.

- The power switch controls power to the capacitors, which take 15-30 seconds to reach full charge.

- The HN switch connects the output to the HV selected by the knobs in the control panel; it allows you to put the power supply in a standby mode.

The high voltage power supplies are switched on in the following sequence:

- Make sure that the High Voltage switch is off (or on "standby") , and that the knobs are all set to zero, and only then move the power switch to the "on" position.

- When the HV ready light comes on, turn the High Voltage switch to "on" and slowly turn up the selector knobs to reach the required voltage. The output voltage is the sum of the knob positions. Watch the meter on the supply to see that the voltage is coming up properly. As you turn up the voltage adjust the trigger level until you begin to see pulses. What is the source of the pulses you see here?

- Check for light leaks as soon as you see a signal by looking at the rate of pulses on the scope (if you have problems finding a signal, un-terminate the scope) while you cover and uncover the detector with a black cloth. If you find evidence of a light leak lower and turn off the high voltage. Examine the surface of the "light-tight" enclosure for possible sources of light leaks and patch them with black electrical tape.

Take a ^{22}Na source from the source cabinet and ask the lab instructor or TA for instructions on handling radioactive sources. Expose the scintillator to the ^{22}Na source and look for signal traces on the scope. You should expect to see very fast (10 to 20 ns width) negative pulses. (Why negative?) For this part you will have to trigger the scope internally. Make sure your oscilloscope input is properly terminated. Record the pulses observed either by making sketches or by photographing the scope face (note vertical and horizontal scale).

Once you are triggering in a stable mode you should remove the source and look for photomultiplier noise pulses. They will have a lower peak voltage with shorter time duration than the ^{22}Na pulses. Record these pulses for comparison with the source pulses on your lab report.

Adjust the vertical and horizontal scope scale to show clearly the signals. Vary the high voltage by 100 volts up and 100 volts down from the nominal setting marked on the tube, typically +750 volts, although some tubes may need higher voltage. Note how much the amplitude changes as a function of voltage.

1.2 Discriminator

Using a T-connector, connect the PMT signal output to the oscilloscope channels and the input of a discriminator. Connect the output of the discriminator to the other channel on the scope so that you can simultaneously view the discriminator output and the photomultiplier tube output. (Properly terminate the discriminator signal!) Set up the scope so that it shows both channels simultaneously.

Adjust the width of the discriminator output pulse to 60 ns, noting its effect on the scope display.

Bring the ^{22}Na source near the plastic scintillator. Check the effect of discriminator threshold setting in two different ways:

- Trigger the scope on the PMT signal, and adjust the scope trigger. Vary the discriminator threshold, and note how the frequency and intensity of the discriminator pulse output signal depends on the threshold setting. You should see that there is a “plateau” of brightness as you reduce the threshold setting from well above the PMT pulse height down to the minimum possible setting. Near the minimum, the trace should brighten considerably, as there you begin to detect noise pulses along with the larger “signal” pulses.

- Use the discriminator output to trigger the scope. Repeat the variation in threshold setting, and notice how the PMT signal changes. As you increase the threshold, you will see a “window” or “hole” underneath the pulses open up, and this window will eventually overtake all of the pulses as you increase the threshold.

The discriminator threshold should be set to maximize the acceptance pulses produced by the radioactive source and minimize the acceptance of the PMT noise pulses. Using the scope to trigger on the output of the discriminator allows you to see where the discriminator threshold is with respect to the PMT's output pulse height. This method is useful for a quick setup, but there is one problem: If you terminate the input on the scope with 50 Ω, the PMT will see a total load of 25 Ω, since the discriminator input itself is also 50 Ω. This will cause (small) reflections, more importantly it will reduce the signal relative to what the discriminator would see without the scope attached. But if you do not terminate the input on the scope, you will cause large reflections, and thus distort the signal seen by the discriminator.

A more reliable method is to use the threshold readout in the discriminator to determine the threshold level you set. Try this by setting the discriminator threshold to eliminate most of the low "noise" pulses. In future labs the threshold should be set using the readout on the discriminator unit whenever possible. If the pulses we wish to select occur infrequently it may be difficult to "see" them using an analog scope.

1.3 Counting Statistics

In this section we use a data acquisition system to record for a fixed time interval the number of pulses from the scintillator counter that will illustrate the time interval dependence of the statistical distribution of the pulses.

1.3 .1 Data Acquisition System

The data acquisition system will not read "fast NIM" pulses, which are very short, negative-going pulses. Instead it requires slow pulses that are compatible with the standard pulse type for TTL logic – a longer, positive-going pulse, nominally 0-5 volts. A "gate generator" or a NIM-TTL converter is used to generate such pulses.

The output of the discriminator is connected to the input of the gate generator or NIM-TTL converter. Observe the TTL output on the oscilloscope and set the width of the TTL pulse to about 0.5 microseconds.

Use a fairly short cable to plug the TTL output into the terminal box connected to the computer. The terminal box sends signals to the counter input on a National Instruments data acquisition card. (Note: TTL signals cannot be sent over long cables without suffering serious signal degradation, unlike properly-terminated fast NIM signals.)

From the computer desktop, start the LabVIEW program called “Interval Counter”. You will see a data set that was left when the last person to use the program shut it off. Click the “CLEAR DATA” button to remove this data. Press the “TAKE DATA” button. After a short delay, you should see the numbers increase in the “Total Counts” window, and if you are lucky, you will see some green bars coming up. Details on how to operate the Interval Counting program are available under the “PROGRAM INFO” button.

1.3.1 Collecting Data

Allow the program to count for a few minutes, until you get about 10,000 counts. As the counting program runs, adjust the “Min counts”, “Max counts” and “Bin width” to see the effect. What happens as you change the “Interval time(s)” control?

Print copies of the histograms for each member of the group for 1 s and 10 s interval times. Also save a copy of each histogram.

In the lab report address the following questions:

a. What shapes *should* the histograms take and do they?
b. What is the standard deviation of the count/interval in each histogram? How does it compare to the mean?
c. How do the fluctuations of the histogram bins depend on the interval time?

1.4 Coincidence counting (see W. R. Leo, Section 15.4, page 310-313)

In most applications of scintillator counters, the experimentalist is interested in recording the occurrence of signals received simultaneously in coincidence in two or more separate scintillator counter systems. We will now set up the counter you assembled and a second scintillation counter system available at your station to record the back-to-back gamma rays emitted by the annihilation of the positron (β^+) from the ^{22}Na source. The β^+ collides with an electron either in the radioactive source itself or plastic case surrounding it, and the two particles annihilate each other. This creates two photons, each with energy equal to the mass of the electron or positron (0.511 MeV). Conservation of momentum ensures that the momenta of the annihilation photons are oppositely directed.

1.4.1 Set-up

Disconnect the cables to the computer acquisition terminal box and NIM-TTL converter or gate generator and set up the NIM counter/timer unit.

The controls on the NIM counter/timer units are not intuitively obvious. To make the unit count for a fixed length of time you need to select a “time base” and then a unit and exponent under the “preset” controls. Each counting period will correspond to $M \times 10^N$ (or $M\ N \times 10^P$) counts of the time-base unit. Try a few settings and use your watch to check timing to make sure you understand how to use the unit.

Connect the second counter to the high-voltage supply and the signal output to the scope input and a second discriminator channel input. Use the radioactive source to set the discriminator level using the same method used earlier.

Set the two counters with a tray so that they face each other as shown in Fig. 3 and place the ^{22}Na source between the two. Trigger the oscilloscope on the output of one discriminator and look at the output of the other. Notice the correlation in time between the two pulses. You may need to fine tune the discriminator levels to see the coincident pulses.

From the oscilloscope observations, determine if the time difference between the two outputs is stable. If not, note the approximate time jitter. Discuss your observations and factors that may contribute to the time jitter between them in your lab report.

Look at each discriminator output in turn, by triggering the scope on one and then the other. Set the pulse widths to about 40 ns and connect each discriminator to an input on the logic unit and establish a 2-fold coincidence trigger.

Connect the output of the logic unit to the input of the NIM counter/timer that is set to count continuously. With the source directly between the scintillation detectors, you should observe many counts on the counter/timer. (If not, **ask for help**.)

Carefully pick up the pre-made scintillator detector, and reorient it so that it faces the source at a 90 degree angle from the other detector. Note the change in the number of counts.

Move the coincidence pin from "2" to "1", and note what happens and why. Move the detector back to its original position. Is there a difference in the numbers of counts when the logic unit is set for 1-fold coincidences?

When setting up a coincidence system, three of the important considerations are:

- The pulse sizes available from the counters and the discriminator thresholds need to be appropriately matched to count efficiently the particles you are interested in and to reject photomultiplier noise to the extent possible. Since the useful pulses may have a wide range of amplitudes some compromises may be required.

- The pulses must arrive at the coincidence circuit at the same time with a precision that depends on the time resolution desired.

- The resolution of the coincidence unit (usually set by the width of the incoming pulses) must be wide enough to count efficiently despite time jitter in the input but must be sharp enough to minimize accidental coincidences. The resolution chosen thus depends on the geometry of the counters and on the singles rate and noise rate in each counter.

1.5 Making a delay curve

Make a delay curve using the counting system set up to look at 2-fold coincidences from the back-to-back γs from the ^{22}Na source. Set the pulse width of the discriminator output to about 20 ns.

Use the timer/counter to count the number of coincidences in a fixed time interval (say 10 s). Use a cable-delay box on the output of one of the discriminator channels to vary the delay between it and the other channel. Explore the effective width of the coincidence: Vary the delay in big steps at first to get the general shape and then refine your grid. Plot a curve showing the amount of delay applied against the numbers of counts. Your "delay-curve" should have a flat region and should drop rapidly on each side. (To get "positive" delays, put the cable between the *other* channel and the logic unit. What factors are limiting the time resolution in your set-up?)

Determine the chance of accidental or double coincidences by using the ^{22}Na source. To make this measurement you first determine the singles rate for each counter. To establish the chance coincidence rate you need to introduce a significant time delay between the signals for two counters so that it is larger than the discriminator pulse width.

In the lab report compare your results with what is expected from the singles rate in each counter and the pulse width into the coincidence unit. See Leo, section 15.4, for further information on delay curves and accidentals.

Optional: High-voltage plateau curve

Check the efficiency with which you are counting coincidences by varying the high voltage on each counter individually and plotting the coincidence rate as a function of high voltage. If the pulse heights are relatively uniform you should find a region where the rate is not rapidly changing: a plateau.

Appendix: Coincidence Counting

To maximize trigger efficiency, one usually sets up a coincidence between the counter you are studying and one other counter and varies the high voltage on the counter in question. If the pulse height distribution has a peak the coincidence rate will rise and then flatten out as shown in Leo, fig 9.18. The beginning of the flat region or "plateau" is the place to set the voltage. In some cases the plateau may have an upward slope due to increasing noise or singles counts giving accidental coincidences.

If you have clean signals as you will from the ^{22}Na source, looking at the scintillator output on the scope will immediately tell you if your voltage setting is appropriate. In some cases when the incoming pulses have a large amplitude variation or a high noise level it may be difficult to find a good operating point. This consideration is particularly important in the muon lifetime experiment and especially if you try to do it with a small number of counters.

You can adjust the delays to get the pulses to arrive in time by triggering the scope on one input to the coincidence circuit and looking at both inputs. This preliminary adjustment can give good results but sometimes should be confirmed by a "delay-curve" obtained by counting coincidences as a function of relative delay.

The incoming pulse widths can be set using the scope and the delay-curve will give you the actual time resolution as well as the rate of accidentals. In the situations you have in the lab the accidental rates will be very low but in an accelerator beam where the particles may come in bunches of very short duration or a collider experiment where interactions occur at very high rates this can be quite a problem. How many particles per collider beam crossing can your coincidence arrangement handle? What would be the accidental rate? The shape of the delay curve tells you the minimum resolution that can be achieved. The delay curve will have sloping edges that indicate the time jitter of the input pulses; the flat central region is where the coincidences are being counted with full efficiency. The optimal delay set point is the middle of the flat portion of the delay curve.

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