Instructions for gg Coincidence with ^{22}Na

Overview of the Experiment

^{22}Na is a radioactive element that decays by converting a proton into a neutron: about 90% of the time through β^+ decay and about 10% of the time through the electron capture (EC) process. In the β^+ decay, the proton decays into a neutron by emitting a positron (β^+) and neutrino (ν_e). The positron travels only a short distance before it annihilates with an atomic electron. In order to conserve both energy and momentum, the 2 photons emitted as a result of the annihilation process should be produced "back to back". I.e. the photons are produced with an angle of 180^o to each other. This can be quite useful! You may have heard about a PET (Positron Emission Tomography) scan, but you probably have not performed one in the lab. The goal of this experiment is to detect the gamma rays emitted when the positron is captured and to determine just how accurately one can find the source of the β^+ radiation by trying to measure the angular correlation between the emitted photons.

To detect gamma rays, two scintillation counters are used. When a gamma ray is incident upon the (NaI) scintillation crystal that is sealed within the aluminum casing, electron showers are produced which cause the crystal to scintillate or create photons in a given spectrum. These photons will travel to a photo-multiplier tube (PMT), the brown portion of detector, where the photons are converted into electrons in the photocathode of the PMT. These few electrons are accelerated in the PMT and used to create more, lower energy electrons. These electrons are in turn accelerated and then used to create more, lower energy, electrons. In some PMT's this process can occur more than 12 times with roughly 10e6 electrons being created for each electron created by a photon. (To perform the chain of accelerations, the PMT requires a large voltage (900V), and in general, the PMT can be quite fragile, so it is best to treat them gently and with some respect.) The generated signal after all these electrons are created is still quite weak (on the order of milliVolts) and requires more amplification. Some amplification is done by a preamplifier connected to the base of the PMT. Three cables are connected to the pre-amplifier base: the HV power cable, the signal coaxial cable, and a cable that looks like a serial port cable that is used to deliver power to the preamplifier.

The HV cable plugs into the Ortec 556 HV Power Supply (HVPS). The HV cable from both detectors plug into the same HV supply. Each detector's signal cable and power cable for the preamplifier plug into a "Spectroscopy Amplifier" (Canberra 2020). A detailed description of the nature of amplifiers, in our case a Semi-Gaussian Pulse Shaper, can be found with the lab handout. The specifics about the Canberra 2020 can also be found in the supplemental material on the web site. Generally speaking, the spectroscopy amplifier takes the signal and provides a nice, smooth, semi-gaussian shape of specific time width, amplified to a desired voltage.

If the experimental setup is dominated by the signals coming from the ^{22}Na decay, you can expect to see a fairly distinct line (voltage pulse) due to the annihilation photons, and a perhaps a less distinct, but higher pulse height line coming from the de-excitation of the ^{22}Na nucleus. Each annihilation photon has an energy of 511 keV, and each de-excitation photon has an energy of 1274 keV. Since there is a linear relation between voltage on the oscilloscope and the energy of the detected gamma ray, and you set the amplifier to give about a 2V signal for the 511 keV peak, the biggest pulse heights that occur with any appreciable frequency will have a height of around 5V due to the 1274 keV photon.

To properly measure the coincidence, you need to select the signal that came from the 511 keV (positron annihilation) gamma ray. This selection can be done with the Single Channel Analyzer (SCA). Unlike the trigger on a scope, the SCA can trigger (send out a logic pulse) when the pulse height of a signal lies between the lower setting of the SCA and the upper setting of the SCA. Thus, in this experiment, the lower level setting defines a minimum *energy* requirement, and the upper level setting defines a maximum energy requirement. When a signal within the energy "window" is received, a "TRUE" logic pulse is sent through the SCA output. By adjusting the settings properly, you can define a small window about the 511 keV gamma ray and thereby selecting primarily the annihilation photons.

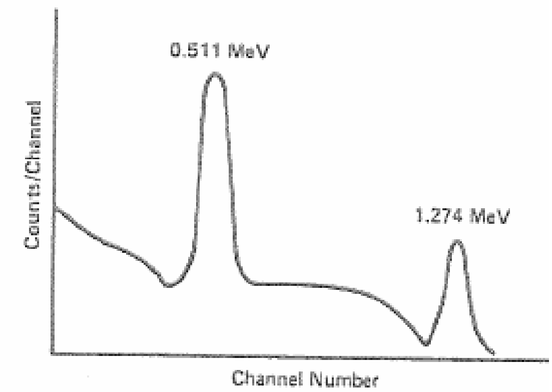
With the two detectors selecting only 511 keV photons, you need to count how many times both detectors see a photon, or how often the two signals are in coincidence. A universal coincidence module will be used. If two "TRUE" pulses are received in a certain time window by the coincidence module, the coincidence module will send out another "TRUE" pulse. These output pulses are then counted by the visual counting module. Since you are trying to measure the rate of coincidence, you must keep track of the time while counting is performed.

<u>Setting the correct amplification</u> (step 1)

The PMT signal enters the Spectroscopy Amplifier through a connection in the back of the NIM module. In the front, the two dials at the top of the module adjust the amplification. The unit has a unipolar and bipolar output. For this experiment, you will use the unipolar output. You should connect the output to channel 1 on the oscilloscope. The channel 1 setting should be 1 or 2V/division. The trigger mode should be set to trigger on channel 1. The time scale should be set from 1-10μs.

At this point, you need to make sure all the settings on your HVPS and Spec Amp are at their lowest voltage and amplification settings. Now, you should set the voltage to 900V on the HVPS. If the scope is triggering properly, you will see multiple faint traces on the screen that seem to be shifting and constantly changing. Depending on the amplification, you may need to adjust the channel 1 setting to see a signal.

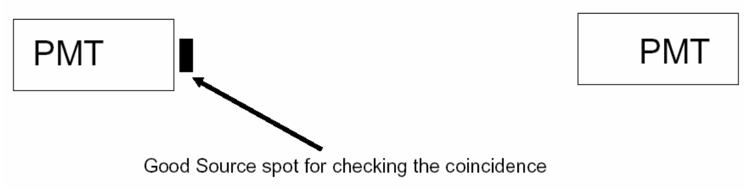
The more often a trace occurs, the darker and thicker it tends to look on the scope. If you refer to figure below of the spectrum of photons detected coming from a ^{22}Na source, you will notice that the 511 keV peak occurs more frequently.



Therefore, the brightest trace you see on the scope when the ^{22}Na source is place near the scintillator end of the PMT assembly is the 511 keV signal. You may also notice a trace with a peak voltage about 2-3 times larger than the 511 keV signal, but occurring less frequently. That peak is the 1274 keV peak. You should adjust the amplifier knobs so the 511 keV peak is about 2 V. You will need to repeat this procedure for both PMT signals coming from the spectroscopy amplifiers.

<u>Calibrating the Single Channel Analyzer</u> (step 2)

Leaving the settings from above intact, you need to connect the unipolar output of the spectroscopy amplifier to the SCA input. The SCA "Lower Level" should be set to 0.0V (the minimum) and the "Upper Level" should be set to 10.0V (the maximum). Now you are ready to optimize the window of the SCA to try to accept mostly the 511 keV photons. There is a neat trick to do this. Plug the output of the SCA you are trying to optimize into channel 2 of the scope and trigger on channel 2. Next, take the cable coming from the output of the spectroscopy amplifier, split it with a "T". You'll need to add an extra cable to do this. The little piece of the "T" is now plugged into channel 1 of the scope, and the extra cable is plugged back into the input of the SCA. This lets you peak on the output of the spectroscopy amplifier without changing the input to the SCA. Now watch the signal on channel 1 as you trigger on channel 2 and raise the lower window on the SCA. You should see the smaller channel 1 pulse heights disappearing from the scope as you turn the knob (may take a few turns). You can likewise adjust the upper window and zero in on just accepting the 511 keV signal. A word of advice is to make a fairly generous widow so that the setup is insensitive to small variations in the gain etc. Do this for both PMT/Spectroscopy Amplifier/SCA chains. When you are done with the second SCA, take the output of the first SCA and plug it into channel 1. It may take a bit, but you should see some logic pulses that arrive at the same time. If they arrive at slightly different times, use the delay knobs on the SCA modules to match them up. Also, it is a good idea to have the ^{22}Na source somewhere in-between the PMT's.

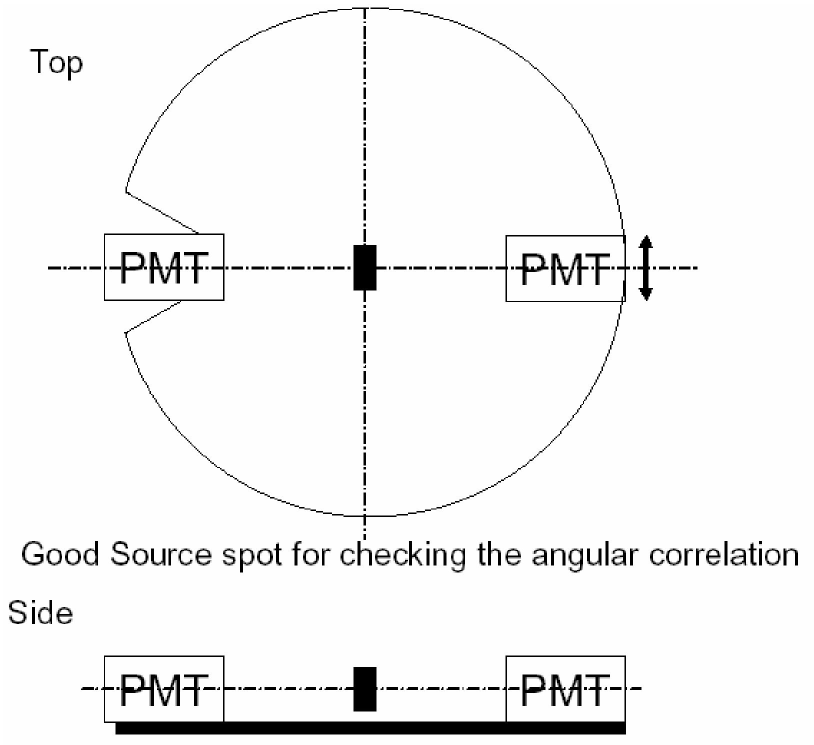


Using the coincidence module (step 3)

Now that the outputs from the 2 SCA's are occurring at roughly the same time, every once in a while, you can plug the SCA outputs into the coincidence module. This module takes several logic input pulses and will produce a single logic pulse out if the conditions set are met. For this experiment, plug the SCA outputs into channels of the coincidence module that are "on" = coinc and set the logic requirement to "2": 2 channels must be on at the same time for a logic pulse to occur. Now you can plug the output of the coincidence register into the counting module and try to start your experiment.

Optimizing your physical setup (step 4)

Placing the source in the center of rotation in the table, knowing where all the PMT's are, and measuring of the dimensions involved is important. In making your measurements of the setup, consider the questions raised in the appendix. You need to anyway for your report.



Making your measurement (step 5)

Placing the source in the center of rotation in the table, knowing where all the PMT's are, and measuring of the dimensions involved is important. In making your measurements of the setup, consider the questions raised in the appendix. You need to anyway for your report.

Take your first measurement at 0 degrees (PMT's directly opposite). Try to get a couple of thousand counts and use this same time period for each measurement. You may have to do a calculation of the time period to use if you are running short on time though. One suggested data taking schema is shown below. It will ease your data analysis to take points symmetric about 0 degrees, and with the same time period. (Do you know why?)

Angle	Counts/s	Angle	Counts/s
0			
1		-1	
2		-2	
3		-3	
4		-4	
5		-5	
6		-6	
7		-7	
8		-8	
10		-10	
14		-14	
20		-20	
25		-25	

What to expect and analysis (step 5)

If you were to make a detailed calculation of the overlap of the areas of the PMTs and the source position for photons emitted 180 degrees apart, you would get something that looked, symmetric and roughly triangular in shape for the estimate of how the counts/s vary with angle. This is important, it lets us perform a simple average where we are trying to find the center of the distribution of counts on the angle axis. There is a detailed example on the web page of finding the average of a histogram. The example used is how to find the average grade in a class. This method is a bit more sophisticated than finding the "center of mass" of the histogram of the data, and gives you an estimate of the statistical error of the average as well as the value. Please include all the information leading up to your estimate of the average angle an its error. Comment on any differences from what is expected, You are also require to address all the questions raised in the appendix: Questions for the gamma-gamma Coincidence Expt.

Can you understand the width of your $\gamma\gamma$ Coincidence Peak?
Med Webster, February 2, 2004

The simplifying assumptions we use in describing this experiment are that:

1. The positron emitted in the Na^{22} decay stops very close to the center of the plastic disk and then annihilates with an electron which is also at rest; the the sum of the electron and positron momenta before annihilation is zero, so the sum of the two γ momenta is zero and they must be back to back.
2. The detector and source geometry is such that both γs will be counted only when the detectors are almost exactly on opposite sides of the source.

The first of these is an assumption about the physics of the annihilation and the second is an idealization which makes the motivation for the experiment easy to explain, but is meaningless without a qualifier about how well the apparatus can test the physics assumption. The purpose of this experiment is both to give you a qualitative introduction to one of the more fascinating aspects of nuclear decay and to let you develop a perspective on how one tests ideas about particles which we are unable to "see" directly. The following questions are offered as a guide to help you explain how well this experiment tests the physics assumption - effectively this is putting an error on the back-to-back result and illustrating the trade-offs which must be made in designing an experiment.

A more advanced discussion would include an estimate of the distribution of distances a positron from this decay travels before it looses all its energy and stops and of the probability of annihilation in flight. These calculations are beyond the scope of this course, so we will pose the point source and at rest annihilation as questions for experimental check.

1. Is your peak at 180°? What sort of experimental errors would lead to a peak displaced from 180°?
2. If your peak were exactly at 180°, what is the physical effect which would make a change in coincidence rate if you moved one of the counters slightly off the 180° position? How much would you have to move the counter to make a coincidence impossible? Does this explain the width of your peak?
3. In answering the previous question you had to use some distances which you measured assuming that the source was directly on the rotation axis of the movable counter. Are these distances the correct ones to use if the source is not accurately on the axis? Make a sketch of the apparatus to make your point and comment (no calculation) if the distances you measured are good enough for an error calculation. Does this last answer depend upon how close your peak is to 180°?
4. There is nothing about the source (no magnetic field for example) to make one direction different from others, so we expect the direction of the gammas to be isotropic (no angular dependence). What fraction of the annihilations would make coincidences if both detectors were 100% efficient? Why don't we do the experiment with smaller detectors so that we get a narrower coincidence angular peak and a stronger statement about the back-to-back hypothesis?