Phys 471 – MODERN EXPERIMENTAL PHYSICS II

Lab 3 – γ-γ Angular Correlation Experiment

I. INTRODUCTION

The Gamma-Gamma equipment will make use of a dual setup of NaI (Sodium-Iodide) scintillators, Photo Multiplier Tubes (PMTs), Pre-amplifiers and Amplifiers to perform the experiment of observing the angular correlation of radiation emitted from decaying isotopes, namely Cobalt 60 and Sodium 20. This is not asked of you out of general curiosity, the relationship between the angles of emitted radiation from decaying nuclei provides a (relatively) straightforward and easily repeatable experimental insight into the quantum nature of radioactive decays and provides information on quantum numbers (angular momentum) assigned to the nucleus of the radiation material under study.

Not only will this experiment give you a strong experimental insight into theoretical material covered in classes such as Quantum Mechanics and Nuclear Physics, but you will become intimately familiar with the operational understanding of radioactive sources, crystal scintillators, PMTs, analog amplifiers, and a tool chest of high energy and nuclear physics equipment. You will inevitably become as familiar with the operation of your digital oscilloscope as you currently are with your calculator of choice. You will push the technical limitations of some of your equipment, and find other equipment lacking. You will observe the happenings of your equipment over timescales from 5 nanoseconds to 8 hours.

Hopefully, this experiment will build your appreciation and understanding of that which is required of the technology, techniques, and technicians behind the advances in experimental nuclear and particle physics. Equipment such as this is often the nuts and bolts of your Professor's research; their experience will be an invaluable resource to draw upon.

Reading

It is very important that you carefully read Sec. 9.5 of Melissinos and Napolitano. In addition, you will need to consult the manuals for all instruments, including PMTs.

II. EQUIPMENT LIST

You will be using PMTs, high voltage sources, radiation sources, oscilloscope and a variety of NIM modules in this experiment. A list of some of these pieces of equipment follows:

1. Two Bicron/ORTEC 2M2/2 PMT and Sodium-Iodide (NaI) crystal detectors;
2. Two ORTEC Model 266 PMT bases;
3. Two ORTEC Model 113 preamplifiers;
4. Two NIM amplifiers, such as ORTEC Model 571 and Model 672;
5. Two high voltage supplies, such as Power Design Model or John Fluke Model 413C;
6. Phillips NIM 710 Octal Discriminator, Phillips NIM 755 Four-Fold Coincidence Unit;
7. Ortec 772 NIM Counter, Canberra 2072A NIM Dual Counter;

8. Tektronix Model TDS-2022 Oscilloscope;
9. *Optional:* PGT MCA 8000 multi-channel analyzer and Dell laptop.

PMT
Connect each PMT to a power supply using RG 59-U cables with proper connectors, and to the oscilloscope (scope) using RG-53-U (or any 50 Ohm terminated) cables with proper connectors. Ensure you are using the two ORTEC PMT units, as they are the newer than the RCA units and should have better noise characteristics. The Toshiba units produce signals different in appearance and amplitude.

Important notes:
1. Be careful while handling the PMT-crystal combination, as the crystal is fragile and could shatter, and the PMT is a delicate instrument. So for example, should you find in a later part of the experiment that lead shielding is required, you must be absolutely sure that the lead is properly positioned to not come into direct contact with any part of the NaI-crystal+PMT combination, and that the lead is mounted extremely stably.

2. NaI detectors call for positively biased High Voltage (HV) power, between 500 and 800V. Make sure to have the bias set correctly to on the power supply unities.

III. SETUP

A good experimentalist always carefully checks over their apparatus prior to beginning a measurement. You should investigate the performance of the detectors and electronics both with a radioactive source and with background radiation from naturally occurring elements and contamination, as well as cosmic rays from the upper atmosphere known as muons. Experiment with placing the source in different geometries and different positions around the PMT and note how this affects the counting rate in comparison to the natural background rate.

- Start the HV initially at 500V. Acquire the signal on the scope. Set the scope to trigger on the falling edge of a negatively biased signal. If you can not get this to work, consult your instructor for help.

- Note the maximum amplitude, rise time, total time, the noise level, and other properties of the signals being observed, as these characteristics will be relevant for your investigations.

- Raise the HV in steps, the HV is not to exceed 800V. Note in your logbook how the shape of the signals change as the voltage is changed. Take at least two snapshots of these signals using the Flash memory card provided by your instructor. Put at least the first and last in your logbook for referencing.

- Repeat this process with the second PMT and crystal combination. Note any differences you may notice between the signals produced by each crystal, print off photos for reference.

- Insert the PMT signal into the preamplifier. Ensure the preamp is properly powered by one of the amplifiers in the electronic stack.

You may want to use the Phillips 744 Fan-in Fan-out NIM module so you can simultaneously view the signal before and after pre-amplification. Consult the device manual if you cannot discern its operation.

- Use the scope to determine the level of pre-amplification provided and any other differences introduced by the pre-amplification of the signal. Repeat this for the second PMT.

- Switch power supplies between the pre-amplifiers and note any differences you see in the signals from the initial orientation.

**** If one orientation has more systematic low level noise it may be best to use the lower noise orientation. The noise seems to crops up sometimes, depending on the positioning of the equipment and matching of the preamplifier to power supply.**

- Next, feed the signal into the amplifier after the preamp and utilize the fan-in fan-out to investigate how the amplifier affects the signal.

- There are many settings on the amplifier that can be used in concert with each other. This can make it hard to tell where to start exploring the options. One possible choice of settings to start with might be:

  Input Mode: Div 10 Neg
  Course Gain: 8
  Fine Gain: 4
  1st Differentiation: Off
  Integration: Off
  2nd Differentiation: Off

- After recording and noting how the settings affect the signal, start altering them from the top of the list to the bottom, noting how they affect the signal by concurrently viewing the pre-amplified signal. You may want to return a setting back to the default before moving on to the next one. Repeat this procedure for both amplifiers.

- If the MCA and Dell laptop are available, take a quick look at the ADC spectrum to ensure the expected peaks from the radioactive source are observed with good resolution. If you are able to make this check, keep a copy of the spectrum for your records.

In order to reduce the effect of random background in your measurement, aim for amplifier settings which result in a relatively steep leading edge of the pulse. This will reduce “time walk” effects from the use of the leading edge discriminator, and so allow a shorter resolving coincidence resolving time to be used.

Read the instructions for the discriminator unit, and feed the amplified signal into it. Note that the discriminator unit will only analyze one polarity of signal properly.

- Observe the signal that is generated by the discriminator in response to the shape of the initial signal. Adjust the gate Threshold (T) and gate Width (W) on the unit and observe what effect this has on the signal (gate) outputted by the discriminator unit.

- Repeat this experimentation with the second PMT signal using another discriminator. You may want to connect the output of the discriminator to the dual counter unit to assist you in quantifying counting rates.

- Experiment with the amplifier settings and the discriminator thresholds to determine the optimal settings for achieving the highest counting rate while minimize background noise in the amplified signal. You can use the adjustable trigger on the scope to experiment with what counting output various levels of threshold will have.

- Once you have a coincidence output from both PMTs, place them equidistant from the source holder. Ensure they are as close as possible to pointing their front faces directly to the source holder.

- Position the scintillators across from each other on the apparatus. Place the strong ^{22}Na source at the center.

- Use the instructions in the **'Coincidence Delay'** appendix to guide you in producing a meaningful coincidence unit output.

IV. CALIBRATIONS, DATA ACQUISITION AND ANALYSIS

- Take measurements of the counting rate of the setup with different positions of the mobile PMT to ascertain the angular correlation, if any, of the gamma rays emitted by the ^{22}Na source. Data points may have to be taken more densely near any areas of interest to gain a clearer picture from the data.

- The sign that this has been done well is that the coincidence rate is dramatically lower when the detectors are perpendicular than when they are across from each other with the source placed at the center. See Fig. 9.33 in Melissinos & Napolitano for a good example. If you find a significantly weaker angular correlation, something is wrong and you need to further optimize the background rate, following the suggestions in that text.

- You should also find the coincidence plateau to be flat and that the coincidence rate drops dramatically on either side of the plateau. See Fig. 9.32 in Melissinos & Napolitano for a good example. If your coincidence plateau is not particularly sharp, or thecoincidence rate outside the plateau is not significantly less than the rate inside the plateau, you should to investigate further.

- Place the detectors back in the same places you used them in the ^{22}Na portion of the experiment, and place the strong ^{60}Co source in the source holder.

- Take counting rate data from both detectors, as well as the rate of coincidence. Take a survey of quick data at 90 and 180 degrees to see if a difference of counting rate can consistently be detected above the associated errors of the rates.

- Hopefully you find the expected difference in the counting rates. In this case, you may proceed with your main data taking. Otherwise, you might need to further optimize the electronics settings. If you make changes, you will likely have to re-measure the coincidence resolving time.

- Calculate the true counting rate and the associated error at positions from 90 to 180 degrees, in 15 degree intervals or smaller, and graph this data. Calculate the ratio of each counting rate to the counting rate at 90 degrees.

- Graph these data and compare them to the expected shape from theory and other experimental trials.

****Important things for students to learn/know before/while doing this experiment are:**

- **Label your cabling,** make it easy to identify which cables come from/go to where. Even if this is only so that your professor or fellow students/lab partners have an easy time identifying what is occurring.

- **Make liberal and intelligent use of the fan-in/fan-out.** This allows you to quickly and easily view a signal before you feed it into a piece of electronics and after it comes out. This is indispensably convenient and necessary both while building your setup, and while monitoring it.

- **What really matters is signal to noise ratio, and getting a reasonably high enough counting rate so the data can be taken over a reasonable period of time.** Electronic voltages can wander over long periods of time; other effects can come into play that will creep into your data if your counting period is too long, or your thresholds too low. It does you no good to try and eliminate all noise, because you will often be eliminating as much or more signal, thus increasing your counting timescale and introducing new sources of error without producing higher quality data.

- **Know and make use of your radiation safety knowledge.** These guidelines are not arbitrary, and if you don't understand the reasoning behind some, it is best to ask for clarification rather than simply ignoring them. These measures are a small price to pay to minimize your dose and eliminate as much of the associated radiological risks. Achieving reliable results in a reasonable amount of lab time requires the use of fairly strong gamma ray sources that should be touched or approached as little as possible. Your best safety equipment is distance from the source.

APPENDIX 1. INSTRUCTIONS FOR SETTING THE COINCIDENCE DELAY

(At this point, it is assumed that the student has successfully created two discriminator logic signals that accurately reflect the number of actual counts coming into the two NaI detectors, and are now trying to achieve accurate coincidence rate measurements. It is also assumed the student has connected an output of the coincidence logic to a NIM Counter.)

At this time, the signals from coincidental gamma rays from the centrally positioned ^{22}Na source are not arriving coincidentally in the electronics of this experiment. Differences in the arrival times of these signals can arise from a number of factors, including minor differences in the positioning of the detectors with respect to the source. The finite size of the source creates an ambiguity in precisely where within the source the gamma rays are emitted from. Differences in the lengths of cabling used in the manipulation of the signals introduce delays in the various electronics along the pathway. These differences in path-length can be altered through the use of additional lengths of cable or electronic Delay Units.

To find the best amount of delay to be added, it is best to make use of the fact that many true coincidences will be found when the detectors are in the 0/180 degree orientation, and very few when in the 0/90 orientation due to the angular correlation of the gamma rays emitted by a ^{22}Nasource. When doing this, it is best to start with the discriminator signal widths fairly wide (~100ns), so that by positioning the detectors in the 0/180 degree orientation and watching the coincidence count rate while altering the amount of delay you have introduced into one signal or another, a region in which coincidences are being counted can be found. This region should not be subtle to find.

Once the region has been located, a more subtle survey of how various delays affect the count rate can be taken.

After the appropriate delay has been added to the circuit, it is suggested that you decrease the widths of the Discriminator gates, in order to reduce the coincidence resolving time. Narrower gates will have the result of reducing the random coincidence rate from events other than the source of interest. Take into account the minimum resolving time of the Logic Unit in selecting the final discriminator gate width. Consult with the Instructor on what may be the best discriminator gate widths.

The coincidence plateau width should be comparable to the width of the widest gate you have set. When selecting your final operating delay, it is suggested that a delay near the centre of the plateau is used, as this will provide protection from time jittering of the coincidence signal. See Figs. 9.32 and 9.33 of Melissinos and Napolitano for examples of properly set coincidence circuitry.

As shown in Fig. 9.32, the coincidence resolving time is equal to the full-width at half-maximum of the coincidence plateau. This value should be used throughout the ^{60}Co portion of the experiment to estimate the rate of accidental coincidences to be subtracted from the total counting value

APPENDIX II. ALTERNATIVE METHOD FOR DETERMINING THE COINCIDENCE RESOLVING TIME

A second way to determine the resolving time requires two separate sources of roughly equal strength. The PMTs should be moved away from each other such that each are only exposed to one source each. Lead shielding and distance can be used to achieve this. Next, the counting rate of each PMT, as well as the rate of their coincidence should be recorded with the sources at a variety of distances from the PMTs, with the counting rate of each PMT kept roughly the same.

Use the equation { T = Coincidence/(Rate1*Rate2) } where T is the resolving time. Repeated calculations of this should be taken, then their values averaged to determine the value and associated error of the resolving time. This value should come close to the resolving time determined in Appendix I.