GAMMA-GAMMA CORRELATION

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QUESTION TO BE INVESTIGATED:

What is the angular correlation between two gamma rays emitted by a single decay event?

INTRODUCTION & THEORY:

Melissinos and Napolitano provide an adequate introduction to this experiment in section 9.5 of their text.

EXPERIMENT:

Calibrate the PMT to the MCA

Set up the two photomultiplier tubes (PMT's) as shown in Figure 1. Set the amplifier gain to approximately 8. Use the BNC input on the back of the computer. Launch the PCA II program on the computer. Set the number of channels to 1024. For each of the PMT's, acquire pulse height data and observe the two high energy peaks of the Co-60 source. Adjust the gain to center the more energetic (rightmost) of the two peaks, around channel 500. This calibration will be repeated before the data run for each angle. If the peak has moved more than 1 channel, the amplifier gain is adjusted to reset it to channel 500.

The spectrum that you observe consists of 1024 points along the horizontal axis. Each point represents a slice (window) in detector pulse height (photon energy). Thus the energy of the ith bin corresponds to some value $E_i \pm DE$. DE is chosen (internally in the MCA) so that the bins have no gaps or overlaps in energy. This is commonly known as a histogram.

NOTE: AS THE HV DIVIDER attached to the PMT WARMS UP, IT WARMS THE SCINTILLATOR, THE OUTPUT OF WHICH IN TURN WILL DRIFT. WARM-UP TAKES ABOUT 1 HOUR.

<u>Calibrate the TSCA:</u>

The second part of the procedure consists of setting the timing single channel analyzer (TSCA) so that only events from either of the two gamma decays are counted. Note that this can (and must) be done to both TSCAs in parallel (i.e., at the same time).

a)   Disconnect the computer and set up the scaling apparatus as shown in figure 2.

b)   Set the TSCA to window mode.

c)   <u>Determining the Ideal Counting Rate</u>: Set the window to pass all events by setting the baseline to zero, and the window size to the maximum (1,000). Measure the number of events detected in 10 seconds. A gate circuit must be used to precisely count for ten seconds (figure 2). You should get at least 10,000 counts (1,000 Hz). If you get less, find a stronger source or use more than 1 button source. If the source is too strong, move it away from the PMT to get a rate of 1,000-3,000 Hz.

d)   <u>Setting the Baseline</u>: With the window (channel width) remaining at maximum width, count the number of events for ten seconds for baseline settings from 20 to around 600 in steps of 10 (e.g., 20, 30, 40, ...). At each setting, all of those photons with energies higher than the baseline setting and within the maximum as determined by the window will be counted. In order to make a histogram of the number of events

as a function of the baseline setting (energy), you must subtract the count totals for 2 successive settings. Plot these differences versus the value of the lower baseline setting for each subtracted result. For example, you might measure 11,000 counts for a setting of 300 and 10,800 for a setting of 310. The difference of 200 counts corresponds to events within the window of 300 to 310. You now have a histogram showing the number of decays in each range of baseline settings (similar to the MCA but with considerably wider channels). Calculate the errors on each difference and add them to the plot. When the positions of the two high energy peaks are located, set the baseline about 3 peak widths below the lower peak. (Recall the spectrum that was seen on the computer when interpreting this coarser, but equivalent plot.) Setting the lower cutoff too low will result in additional noise, but no additional signal. This setting should be sufficiently low in energy that all photons in the peak trigger an output, even if some drifts in pulse height occur during data acquisition.

e) <u>Setting the Window</u>: Reduce the window width, decrementing from 1000 in steps of 20. Again, take data for ten seconds for each setting as was done with the baseline. The number of counts per measurement will not change much until the peaks are reached. Set the window size so that the upper limit is at least 5 peak widths above the higher energy peak. Why would setting the upper cutoff a bit high not seriously affect the signal or noise? Verify that the final counting rate is reasonable, using the criteria stated in part c.

f) <u>Peak Position</u>: Verify that the peaks have not drifted as described in part 1. If the peaks have moved significantly, you must repeat the window and baseline calibrations described above.

g) <u>TSCA Delay</u>: Measure the delay on each of the PMT circuits. This is most easily done by simultaneously observing the positions of the amplifier and the discriminator outputs on two channels of an oscilloscope (use the amplifier to trigger). The delay of the first TSCA (for the TAC start) should be set to minimum, and the second TSCA (for the TAC stop) should set to a delay of about 500 ns longer than the first.

<u>Data Acquisition</u>:

Connect the discriminator outputs to the TAC start and stop inputs (figure 3).   The output of the TAC should go into the Spectech UCS20 device, which is connected by USB to the PC. Run the Spectech software, and verify that the peak lies in the middle of the spectrum. After checking that the Spectech settings are correct, you may adjust the delay on the second TSCA if it is necessary to center the peak.

Take your first data in sets of 4 equal-length 15 minute runs, one at $90°$, a second and third run at $180°$ (where the effect is largest), then finally a second run at $90°$. Any significant delays between runs will allow the apparatus to drift and thus will cause the results to change significantly. The total live time at $90°$ should be the same as the total live time at $180°$. Since the midpoints of the $90°$ and $180°$ runs are coincidental in time, the effects of drifts in the apparatus are minimized. Analyze the first set of 4 runs before proceeding with additional data acquisition. Compare your results with those in Melissinos.

The peak and background data analysis can be done entirely by MS Excel without having to do any complex fitting. Find the average background that is clearly outside the peak area, including all the background channels that appear statistically constant. Integrate the peak and background channels in the peak region. In any counting experiment, the error on the number of raw counts is simply the square root of the number of raw counts. If you have chosen signal and background regions that

do not overlap, they should be independent (i.e., uncorrelated). Use the two integrals, with appropriate normalizations, to get the number of coincidences counted (peak sum - background sum) and its error.

Using the above results, calculate the ratio of

$$R = \frac{N(\theta)}{N(90°)}$$

for each adjacent pair of angles you took. Estimate the amount of time needed to get an absolute error dR = 0.01 for each angle ratio. It is usually between one and two hours depending upon the source strength and distance from the source to the detectors. All angles should be taken for this amount of time. Measure R for angles from 100 to 180 in steps of 10 degrees. Remember, before collecting data for each angle, check the position of the higher energy peak for the two PMT's, and adjust the amplifiers if necessary. If the timing peak has moved, you have a major problem. It should be totally stable.

Assume that the TAC is dead (i.e. busy) for half the time of its full scale value, each time an accidental start and stop are encountered. Assume that it is dead for 100% of its full scale for all starts with no stops. From this, calculate the fraction of the signal events that are lost at each angle due to this dead time. Correct your data for these lost events. Note that to first order, the correction factor will cancel, since it appears in both the numerator and denominator.

Fit the ratios for each angle to the theory including the uncertainties,

$$a_0 + a_1 \cos^2(\theta) + a_2 \cos^4(\theta)$$

Note that this is simply a polynomial fit of $a+bx+cx^2$ where $x=\cos^2(\theta)$ (and $a=1$). Note whether a_0 agrees with the theoretical value of 1. Make a more accurate calculation of a_1 and a_2 using the knowledge that $a_0 = 1$.

APPENDIX: Glossary & Figures

Amplifier:

This device should be run in positive, bipolar mode. The amplification factor should be about 8.

Timing Single Channel Analyzer:

The single channel analyzer is a device which contains two discriminators. These define a window where an electrical pulse can trigger an output as is shown in Figure 4. The analog (PMT) pulse must be greater than the first discriminator and less than the second to trigger. Any pulses below the lower level or above the upper level are ignored. In window mode, one potentiometer determines the lower level, while the other determines the size of the window, as shown. A timing single channel analyzer does the same filtering, but its output pulse can be delayed by small amounts.

Inverter:

This is simply a 1:1 transformer with the polarity reversed on the secondary coil. The negative-going pulse from the TSCA is flipped over so that it is positive-going.

Discriminator:

Its TTL (digital) output goes positive when its input rises above a given threshold voltage. Hence, an analog pulse is converted to a digital pulse.

Time to Amplitude Converter (TAC):

This device measures the difference between the start and stop pulse. It outputs a pulse with an amplitude proportional to the difference. Typically, the output of a TAC is used as input in an ADC or Multi-Channel Analyzer. It should be triggered externally.
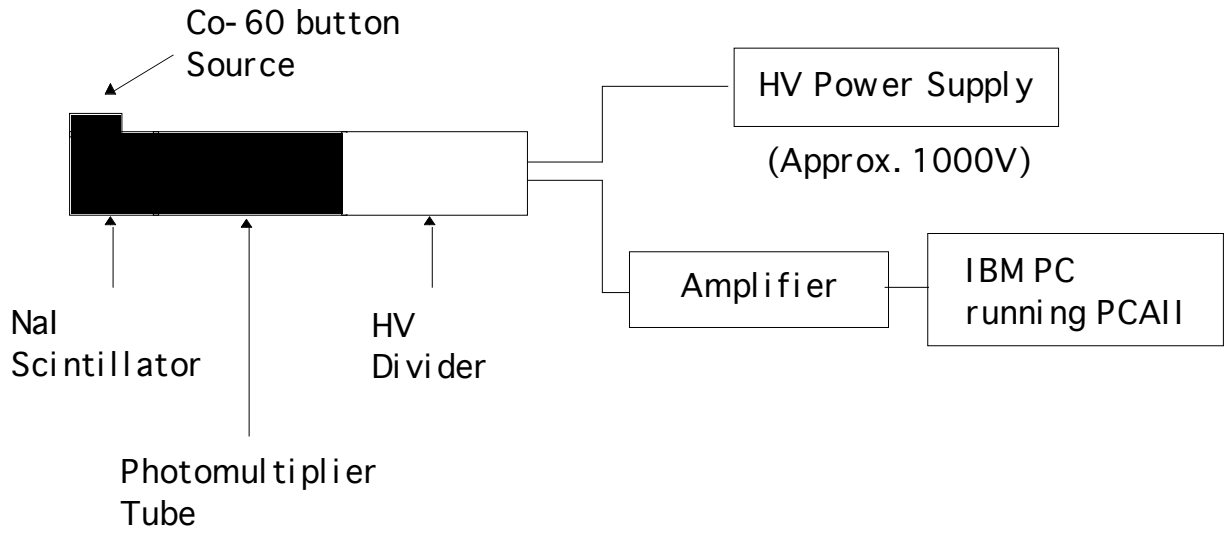
Figure 1. HV and Amplifier Calibration Setup for each PMT.
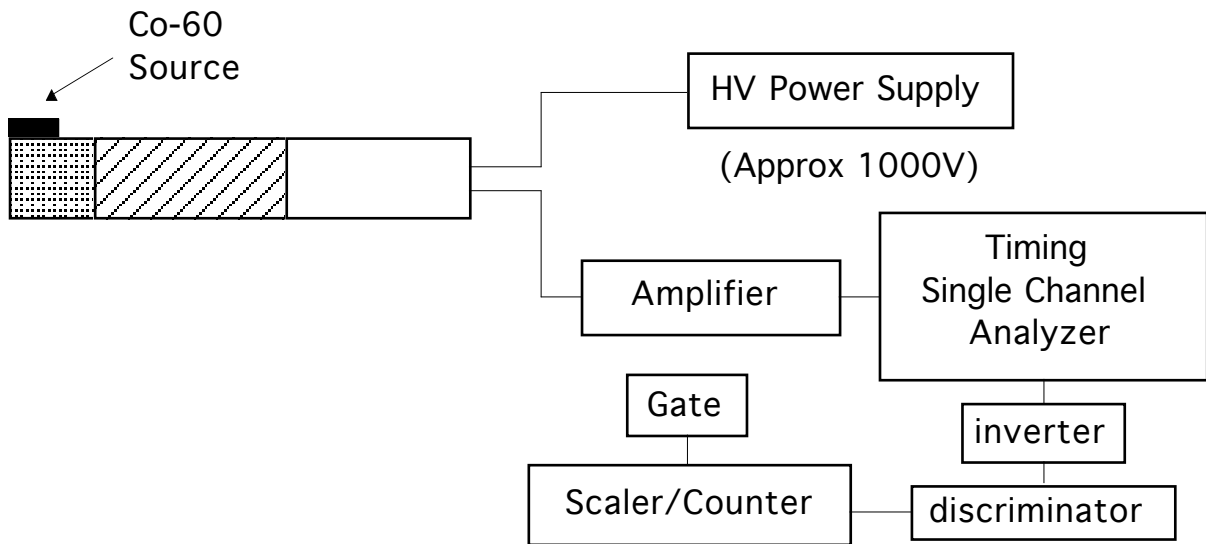

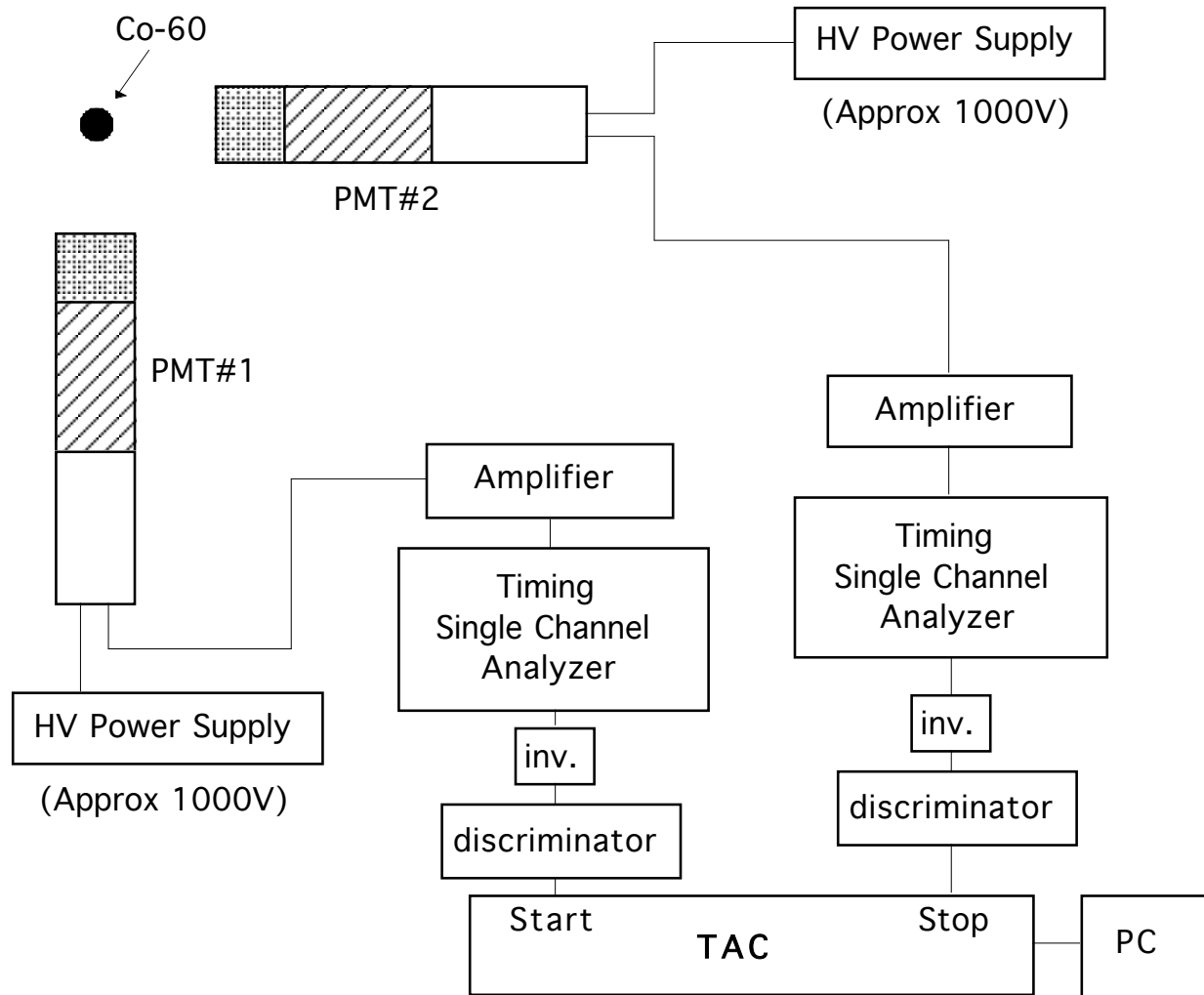Figure 2. TSCA Calibration Setup.
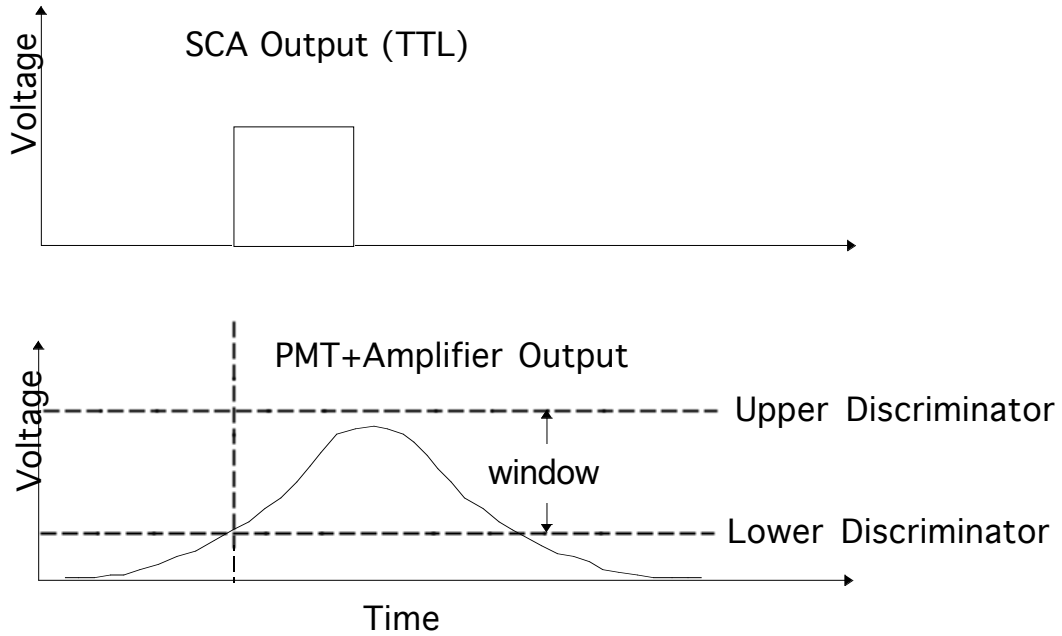
Figure 3. Data Acquisition Setup.

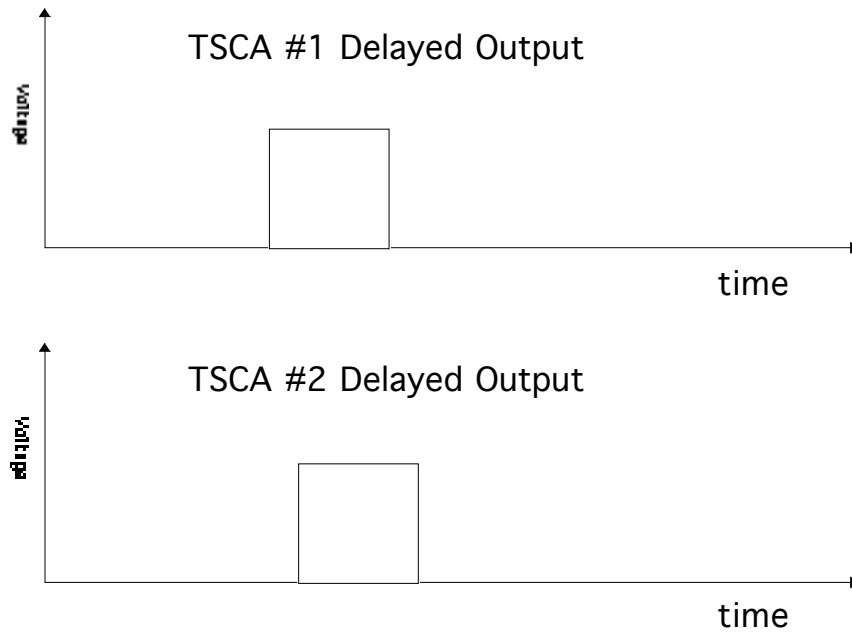Figure 4. Single Channel Analyzer Operation.

Figure 5. Timing of Inputs to the Time to Amplitude Converter (TAC).