Experiment II Counting Statistics and Energy Measurement

In this experiment we will study the effects of statistical fluctuations in counting experiments and measure the distributions of intervals between successive random events. We will also study the gain of a photomultiplier tube and compare the energy resolution of plastic scintillating material and NaI by observing the output voltage spectrum.

Prior to coming to lab you should open and study the three links Multichannel Analyzer (MCA), Light Pulser and Radioactive Sources found under Laboratory Apparatus Information on my web page. You should have calculated the energy value of the Compton edge of the $^{133}$Ba, $^{137}$Cs and $^{60}$Co sources before coming to the lab.

2.1 Statistics and intervals between successive events

The collection of data in nuclear and elementary particle experiments very often results in measuring distributions of numbers of occurrences vs. some variable, such as time, voltage, energy, etc. In order to interpret the distributions one needs a quantitative estimate of the statistical significance of the data collected. Counting statistics (see lecture 4 and Leo section 4.2) follow Poisson distributions:

$$P_\mu(x) = \frac{e^{-\mu} \mu^x}{x!},$$

$P_\mu(x)$ is the probability of observing $x$ when the mean is $\mu$. It is the limit of the binomial distribution when the probability of a success is very small, $p \to 0$, and number of trials, $N \to \infty$. For Poisson distributions the variance is equal to the mean; that is, $\sigma^2 = \mu$, consequently the standard deviation is $\sigma = \mu^{\frac{1}{2}}$.

For this part of today’s laboratory you will set-up a cosmic ray muon telescope using the three “paddle” scintillator counters, shown below. The first step is to set-up triple coincidences.

Three paddle counters used in the first part of experiment 2
The signals from the counters should be in time but you will need to verify that before taking data. There are three stations of paddle counters. One group will begin with 2.2 until a station is available. To verify that the signals from the three counters are arriving in coincidence use the two back-to-back γ’s from the $^{22}$Na source as you did in experiment 1. First verify that you have a “good” signal from each photo tube. Next input the phototube outputs to discriminators, set the discriminator level while looking at the pulse from the PM; set the output pulse width from discriminator to about 30 ns and check the timing of counter pairs. Place the $^{22}$Na source between counters A and B and adjust arrival time of their pulses at the coincidence input to be equal at which point A and B are “in time”. Next repeat for B and C by moving source between B and C and you will have scintillators A, B and C set to detect particles that traverse all three counters. In short a triple coincidence.

Once coincidence has been established, remove $^{22}$Na resource so we can measure the distribution of cosmic ray muons. The output of the triple coincidence will then be input to a gate LeCroy 222 gate generator that you should set to give a 50 ns output pulse, which is input to the small box that contains ADC’s. The output goes to a PC and displays the time between detection of a muon 0th event and the detection of the subsequent n-th muon. Observe the data as it comes in and note the large statistical fluctuations when there are only 10’s of counts/bin. Print out distributions for $n = 1, 5, 25, 30$ (i.e., every 5 minutes. In the lab report, discuss the differences between each n-distribution as a function of time. Then compare the different n-distributions to what is expected from statistical analysis.

Collect data for about 20 minutes while you set-up the next part of this lab, section 2.2 Gain as a Function of High Voltage.

### 2.2 Gain as a function of high voltage.

To explore the gain of phototubes we use a light pulser to simulate the light output of the scintillator. The light pulser is a simple instrument in which a capacitor is charged and then discharged through an LED using a Field Effect Transistor (FET) as a switch. The light pulser requires a DC voltage roughly in the +25 to +40 volts range and a positive trigger input pulse of 2-4 volts.

Light pulser circuit (note the green LED bulb) and PM inserted in light pulser enclosure
Connect the pulser supply and trigger voltages. With the voltage at about 25 volts trigger the light pulser and look at the LED to be sure that you observe light pulses. Once you verify that light pulses are visible insert the bare phototube into the pulser housing and tape the end of the housing with the black electrical tape provided to make a light tight seal.

For this experiment you will use the 10 stage Electron Tubes 9266KB photomultiplier tubes available in the laboratory. This tube has a maximum rated voltage of 1000 volts; you can operate it from about 750 to 800 volts. If saturation effects seem to be present reduce the light level of the pulser. One should always look at the pulses on the scope as the voltage is raised for the first time to check for light leaks or abnormal behavior.

Observe the output of the photomultiplier on an oscilloscope. You will need to trigger the scope internally to look at noise. Observe and record the noise pulses as a function of the applied PM tube voltage. These noise pulses do not have a sharply defined pulse height spectrum so consequently your "measurement" of their pulse height will be a very rough estimate. The light pulser will result in a well-defined voltage output of the PM.

For a fixed light pulser voltage plot the peak pulse value as a function of PM high voltage. Four voltage values spaced in range 50 to 100 volts are sufficient to decide whether the behavior is linear or not. How might you plot this to reveal the functional dependence that you expect? For a fixed PM high voltage observe and plot the PM output pulse values as a function of the light pulser supply voltage.

Now you are ready to study the fluctuations of the PM output. Set the light pulser voltage to 25 volts. Connect the output of PM to the input shaping amplifier and the output pulse of the shaping amplifier to the Multichannel analyzer. For this fixed voltage setting collect some tens of thousands pulses and save them to a file and/or print out the distribution. The observed distribution is a measure of the fluctuations of the PM for a fixed light intensity. Use these results to discuss the resolution of the NaI photo-peaks in section 2.3. While these measurements are in progress, part of the group should set up for 2.3.

2.3 Energy Response of a Scintillation Counter

See W. Leo, Ch. 7 and Knoll Ch. 10

To study energy response and energy resolution we will observe gamma rays from the following three sources: $^{133}$Ba, $^{137}$Cs and $^{60}$Co. For these measurements you will use an existing 2-inch thick plastic detector/photomultiplier tube combination (already taped up) and a NaI scintillator PM combination. In your lab report compare the spectra of pulse heights observed from the two scintillator counters for each of the three sources.
Note that the plastic and NaI detectors should be powered from separate high voltage power supplies. The high voltage for the NaI detectors is always +1000 volts.

2.3.1 Comparison of Plastic and NaI

Look at the output pulses from both the plastic scintillating material and the NaI crystal using one of the sources. *Note any differences and explain them in your lab report.*

Connect the output of the plastic and NaI detectors to the 575A NIM module shaping amplifier and adjust the gain of the amplifier so that the maximum pulse height using a $^{137}\text{Cs}$ source is about 3 volts. Check quickly that the pulses from the Cobalt source are not clipped (cut-off because the amplifier saturates). **Use this amplifier gain setting to measure the spectrum of each source for that detector.** Repeat the process for the second detector. *Why do we use shaping amplifiers in this experiment?*

Look on the scope at the output of the scintillation counter and also at the output of the NaI crystal counter.

Use the plastic scintillator to record a pulse height spectrum on the Multi-channel analyzer, MCA, first with the $^{137}\text{Cs}$ source and then with the $^{60}\text{Co}$ source. Transfer each spectrum from the MCA to the computer and print it out for eventual comparison to spectra obtained with the NaI detector. Now use the NaI detector to record a spectrum with each of these sources. You should try to account in a qualitative way for the differences between the spectra you observe in plastic and in NaI. What features of the NaI spectrum show up in the plastic detector spectrum and why?

2.4 Features of the Pulse Height Spectrum
Identify the various features of the $^{133}$Ba, $^{60}$Co and $^{137}$Cs pulse height spectra in NaI. These include the Compton continuum, Compton edge, photo peak and if possible single and double escape peaks. Which of these features measures the energy of the photon? It is very important that you understand completely the photo-peak and the Compton edge and explain these clearly in your lab report. The picture below shows the PC screen using the data card in the PC and the MCA software provided. See the separate web page description of the use of the PC in this mode.

![Image of PC screen showing data card and MCA software]

2.4.1 Energy Scale

Using a NaI crystal and a variety of gamma ray sources that are available establish an energy scale on the pulse height analyzer and draw a line through your data points. Which points on the spectra can you associate with particular energies? Do you observe any non-linearity within your uncertainties?

Determine the energy resolution at each point and make an appropriate plot to help you decide whether the resolution varies according to the simple model of photoelectron statistics (Poisson distribution and number of photoelectrons per unit energy)

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