Scintillation Counting Introduction

Adapted from
http://wanda.fiu.edu/teaching/courses/Modern_lab_manual/scintillator.html

Energetic charged particles traversing scintillating material excite electrons from the valence band to the conduction band, leaving holes in the valence band. When the electrons and holes recombine, light is emitted. The shorter the recombination time, the narrower the pulse, the more pulses per unit time can be distinguished, and, consequently, the higher the particle rate which can be detected. Good quality scintillator quickly, efficiently, and linearly converts particle kinetic energies into light.

Scintillation light can be detected by a photomultiplier tube (PMT) [see Figure 1], which produces a pulse of current whose magnitude is proportional to the number of photons observed. Photons emitted by the scintillator after the transversal of an energetic charged particle can hit the PMT’s photo-cathode and release electrons via the photoelectric effect. The probability for this sequence to occur after particle traversal is about 20%, so, on average, five scintillation photons must be produced to ensure the liberation of one photo-electron. Photo-electrons from the photo-cathode are accelerated toward a metal plate called a dynode. The impact of an electron on a dynode typically releases two electrons, which, in turn, are accelerated to the next dynode. In a multi-stage PMT, then, one photo-electron thus generates roughly $2^N$ electrons, where $N$ is the number of dynode stages. High voltage (HV) is required to accelerate the electrons from dynode to dynode and ultimately to the anode. Notice the multi-stage voltage divider circuit in the PMT. It ensures that each successive dynode is at a more positive potential than is the previous dynode.

The cascaded electrons are collected at the anode as a pulse of current. The amplitude of the pulse is proportional to the number of photo-electrons, which, in turn, is proportional to the number of photons that hit the photo-cathode, which, in turn, is proportional to the amount of light produced by the scintillator, which, in turn, is proportional to the amount of energy deposited in the scintillator by the charged particle. In short, the pulse amplitude is proportional to the energy deposited in the scintillator.

The pulse can be transmitted to electronics which display (an oscilloscope, for example) or amplify and record [see Figure 2] it. One of the most common approaches to recording the pulse is to digitize its amplitude and count the number of pulses with that (or other) amplitude. The digitization (conversion of a continuous value into a discrete value) is accomplished by an analog-to-digital converter (ADC), which assigns numbers (typically between 0 and 1023 or 0 and 2047) to amplitudes. Each instance of an ADC value (also called a channel) can be counted and stored tabularly or displayed in a histogram (ADC value along the abscissa and count—or frequency—along the ordinate). The result after a number of entries is a distribution of the frequency of each ADC channel. Since each channel is related to a pulse amplitude, and the pulse is related to the energy deposited in the scintillator, each
Figure 1: Schematic diagram of a scintillator coupled to a photomultiplier tube (PMT).

Figure 2: Block diagram of a typical data acquisition system.

channel is associated with energy deposition, and the full distribution is known as an energy spectrum.

The association of specific energy values with ADC channels (ultimately, pulse amplitudes) involves a calibration process, determining the empirical relationship between ADC channel (pulse amplitude) and energy.