Experiments with scintillator paddles

1 Aim

1. Finding the operating point of scintillator detectors
2. Plateauing with cosmic ray and other radioactive sources
3. Measurement of efficiency
4. Measurement of cosmic ray flux

2 Items required

1. Scintillator Paddles
2. Radioactive sources (^{137}Cs, ^{60}Co etc.)
3. LEMO and BNC cables
4. HV power supply, Discriminator, Counter/Scaler, Coincidence unit

3 Scintillator Detectors

In scintillation detectors, radiation-induced excitation produces light quanta (photons). A scintillation counting system consists of a scintillator material, a photo-multiplier tube (PMT), a power supply, and an amplifier-analyzer-scaler system. When an ionizing radiation passes

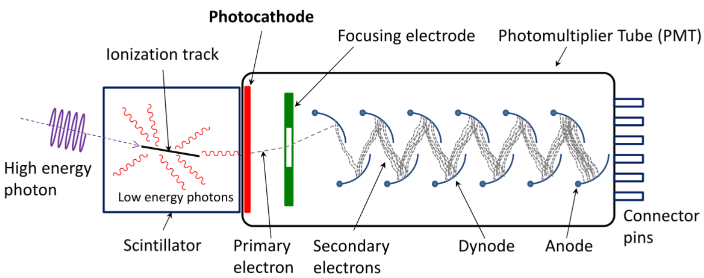

Figure 1: Schematic diagram of a photomultiplier tube. (By Qwerty123uiop, CC BY-SA 3.0, `https://commons.wikimedia.org/w/index.php?curid=62426194`)

through the scintillator material, it produces photons. The number of photons produced is proportional to the energy deposited in the scintillator. The scintillator is covered with a reflector except on the side connected to the PMT. The PMT has a photoelectric film (usually coated onto the photomultiplier tube) as its first element. When light falls on it, electrons are released by the photoelectric effect. The number of electrons produced is proportional to the number of photons falling on the photocathode. The electrons produced are focused onto the first dynode. The dynodes are coated with a material like caesium antimonide so that, when high-energy electrons hit them, secondary electrons are produced and hence electron multiplication occurs. The photomultipliers have 10 or more dynodes (stages). When an electric potential is applied between any two dynodes, the secondary electrons produced in preceding dynodes gain energy before they strike the next dynode and produce more secondary electrons. A voltage divider chain is used to provide gradually increasing potential to the dynodes. Finally, a large number of electrons are collected at the anode giving a signal.

4 Experimental Procedure

All the scintillators must be placed on an aluminium rack or table. The operating voltage and the threshold voltage for the discriminator are set at first. A schematic circuit diagram for counting the singles rate of a scintillator module is shown in Figure 2. The discriminated NIM signals are counted using a NIM scaler.

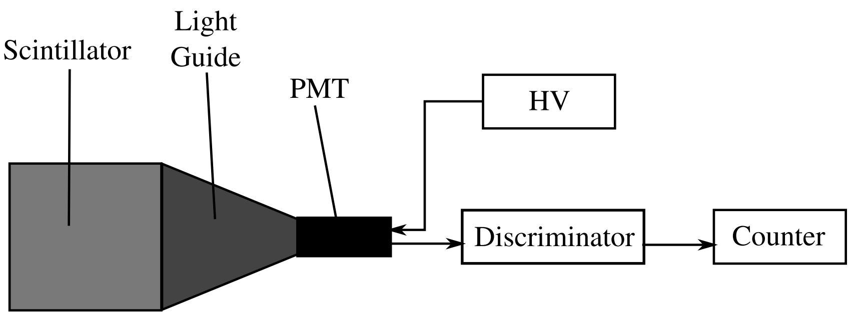

Figure 2: Circuit diagram for counting scintillator detector signals

To get the operating regions of the scintillators, voltage scan and threshold scan have to be done for different radioactive sources.

4.1 Voltage scan

1. Connect the SHV cable (from the power supply) and BNC cable to the scintillator paddle. Connect the BNC cable from the scintillator to the counter with the help of a BNC to LEMO converter and a LEMO cable.

2. Keep the threshold in the discriminator to a nominal value (you can select this value seeing the scintillator detector signal in the oscilloscope) and increase the voltage starting from 1000 V to 1500 V in steps of 50 V.

3. For each voltage setting, count the signals with and without radioactive source for 2 minutes each (You can count for a larger duration for more statistics).

4. Plot the count rate only for source (Count rate with source - Count rate without source) as a function of voltage. The operating voltage is decided from this plot.

Paddle Voltage (V)	Threshold (mV)	Count rate (Hz)

(**a**) Voltage scan readings

Paddle Voltage (V)	Threshold (mV)	Count rate (Hz)

(**b**) Threshold scan readings

4.2 Threshold scan

1. Set the operating voltage as obtained before.
2. Vary the threshold from a low value to a high value with proper steps. For each threshold setting, count the signals with and without radioactive source for 2 minutes each.
3. Plot the count rate only for source (Count rate with source - count rate without source) as a function of voltage. From this plot decide the value of the threshold to be applied.

Repeat the voltage scan and threshold scan for all scintillators.

5 Measurement of relative efficiency and estimating cosmic muon flux

Make an arrangement of scintillators as shown in Figure 3 so that all the scintillators overlap. Measure the overlap area.

Figure 3: Arrangement of scintillator paddles.

1. Set the voltage and threshold for all three detectors as obtained above.
2. Observe the discriminated signals on the oscilloscope to check if the delays are matched. Feed the discriminated signals to a logic module and make the coincidence.
3. Pass the coincidence output to the counter. Count the number of coincident counts for a period of time.

5.1 Relative Efficiency

Two logics are made in the coincidence unit: (a) The discriminated signals of paddle above and below the middle paddle are ANDed. The output is passed to the counter for counting. This is N_{twofold}. (b) The discriminated signal of all three paddles are ANDed. This output is also fed to the counter. This is $N_{\text{threefold}}$. The efficiency of the middle paddle is given by

$$\eta_{\text{rel}} = \frac{N_{\text{threefold}}}{N_{\text{twofold}}} \times 100. \tag{1}$$

One should plot the efficiency versus voltage to obtain the plateau.

5.2 Estimating cosmic muon flux

The average rate of muons at sea level is $\sim$1 $\text{cm}^2\cdot\text{min}^{-1}$. The intensity I, of the muon flux varies with the zenith angle θ as

$$I = I_0 \cos^n \theta \tag{2}$$

where, I_0 is the intensity at zero zenith angle and n is a constant characteristic of the geographical location ($n \approx 2$). The formula in (2) holds for zenith angle $\theta \leq 80°$. The measured value of I_0 closest to the geographical location of the experiment being performed can be obtained from literature.

From the area of the paddle under irradiation and the calculated efficiency, an estimate of the cosmic muon flux can be obtained.