

# Scintillators as an external trigger for cathode strip chambers

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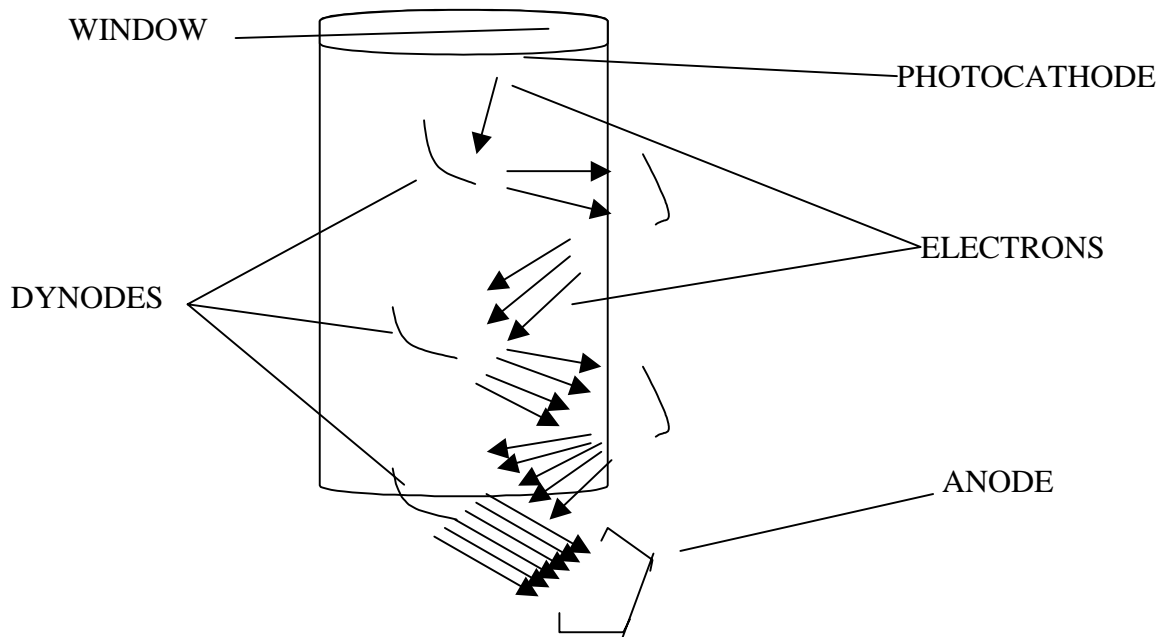
An external trigger was set up to test cathode strip chambers (CSCs) in conjunction with prototype electronics by detecting cosmic-ray muons. The trigger consisted of two organic scintillators, each fitted with a photomultiplier tube (PMT) at both ends and stacked on top of each other, placed underneath the CSC to be tested. This stacked configuration eliminates noise in the PMTs and spurious light emissions within the plastic of the scintillators. The trigger yields a clean count of the number of cosmic particles passing through both scintillators. This same trigger was also used to evaluate 24 organic scintillators, producing plots that describe the amount of spurious light emission in each scintillator as well as the efficiency of and the amount of internal noise in each PMT.

## 1. Introduction

The Compact Muon Solenoid (CMS)<sup>1,2</sup> is a collection of detectors designed to isolate and reconstruct the trajectories of particles given off by a collision of two protons. It is one of four collections of detectors that will operate in a new 14 TeV particle accelerator called the Large Hadron Collider (LHC) under construction at the European Center for Nuclear Research (CERN). The chief goal of CMS is to detect muons around the collision site and infer the reactions through which they may have decayed from a

Higgs Boson, a theoretically proposed particle whose detection will fill a large gap in the Standard Model of particle physics.

One type of detector used by CMS to isolate and track these muons is the cathode strip chamber (CSC)<sup>1,2</sup>. These devices are currently being tested for the first time since being assembled to assure that each works properly. A necessity of any work, including testing of this kind, involving CSCs is a trigger of some kind to tell the device when to take data. It is not desirable to continuously take data because a large portion of it is not interesting and shows merely that no particle was detected. After it has been found to operate within established parameters, each CSC is now also being retested, one at a time, in conjunction with new prototype electronics. Both of these sets of tests use cosmic ray muons, which are incident upon the earth at a flux of about 1 or 2  $\text{s}^{-1}\cdot\text{dm}^{-2}$ .



*Figure 1.* Schematic of PMT components.

## 2. Scintillators and PMTs

My project involved setting up an external trigger for the new test, coordinating one CSC with newly developed electronics. The trigger uses BC-408 plastic scintillators<sup>3</sup> supported on metal frames. The scintillators are planks, approximately 30 cm by 180 cm, and are connected to a Philips XP-2212 photomultiplier tube (PMT) at each end. Fig. 1 is a schematic of the main components of a PMT. Each is fitted with a VD122B type voltage divider that takes a high voltage input and distributes it to the dynodes within the electron multiplier. The necessary voltage to elicit nominal gain from the XP-2212 PMT ranges from 1500V to 2400V.

The plastic in the scintillators emits photons when a charged particle passes through it. This light travels through the scintillator to both ends where it enters the windows of the PMTs. To prevent normal light in the lab from entering as well, the scintillators and PMTs are completely wrapped in black tape. After a photon passes the PMT window, it strikes the photocathode, which responds by emitting electrons. These electrons pass to the first dynode, then to the second, then to the third, and so on to the anode, due to the steadily decreasing electric potentials placed on the dynodes by the divider. Furthermore, when one electron hits a dynode, several more electrons are emitted. An avalanche occurs as the number of electrons increases exponentially. In this way, the scintillator and PMTs convert incident cosmic rays into an electrical signal.

However, noise in the PMT and spontaneous light emission by the plastic of the scintillator can interfere with particle detection. As the applied voltage increases, the multiplier amplifies the small random noise in the electronics of the PMT along with the

electrons caused by light from the scintillator. This amplified noise overshadows much of the signal from the scintillator. Furthermore, light from the scintillator is not always a result of incident charged particles. Often, the plastic in the scintillator emits light spontaneously. This light also enters the PMTs and becomes mingled with the signal.

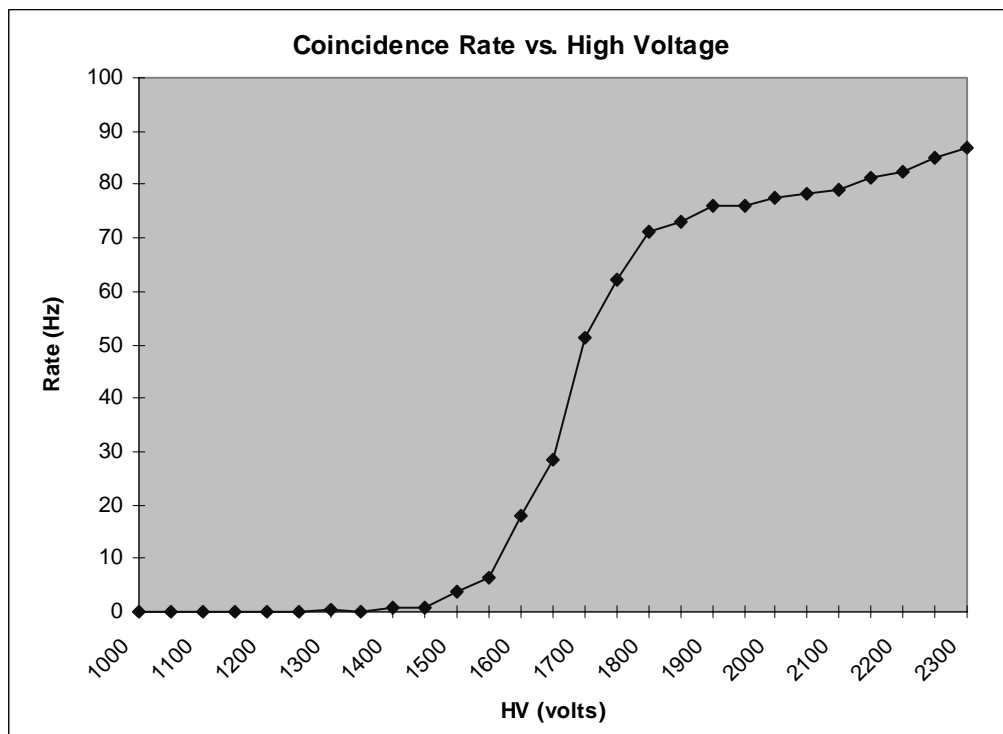
### **3. The Trigger**

The trigger was designed in such a way as to eliminate both PMT noise and spontaneous scintillator emission from the signal. It consisted of two scintillators stacked on top of each other using metal supports. This setup was placed underneath the table on which the CSC lay. By finding coincidences between all four PMTs in this way, it is possible to eliminate electronic noise and spurious light emissions within the scintillators, producing a clean signal representing charged particles passing through the stack and the CSC. Since the CSC was much larger than the scintillators, there was only a small range of incident angles that would put a muon through the trigger and not through the CSC. However, due to the nature and goals of the testing being done, this negligible occurrence did not matter.

The output signal from each PMT was run through a Phillips Scientific model 730, tri-mode discriminator. The discriminator converts an input signal, like the ones created by the PMTs, into a series of pulses, each of fixed width and amplitude. A pulse is created if the signal falls within variable thresholds. The lower level threshold was adjusted to 15.0 mV and the upper level threshold to 10.0 V. The width of each pulse was set to 150 ns. It is necessary that the cables used to bring the signal from the PMTs

to the discriminator are the same length to prevent complications resulting from the information about one muon in the PMT arriving sooner than the information about the same muon from another PMT.

From the discriminator, the four signals were sent to a LeCroy Model 465 coincidence unit. The single output signal was then fed to a counter where, counting the number of output pulses after 300 s, I calculated the incidence rates measured by the trigger when supplied with voltages increasing in increments of 50 V from 1100 V to 2300 V. Plotting the rates versus voltage generated a graph from which I determined that 2000 V would be an appropriate voltage to achieve the best efficiency of the trigger without supplying more power than necessary to the PMTs (see Fig. 2).



*Figure 2.* Plot of the coincidence rate measured by the scintillator trigger versus high voltage.

### 3. Testing Scintillators and PMTs

My project also included testing 24 scintillators, numbered consecutively 1-24, and their PMTs, also numbered 1-48. The tests, using cosmic rays and the trigger set up previously, produced graphs of the incidence rates measured by each PMT and their efficiencies versus the high voltage applied to them. From these plots, we can see the amount of spurious light emission in each scintillator, the amount of noise in each PMT, and the minimum voltage necessary to achieve maximum efficiency.

The scintillators used in the trigger for these tests were #13 and #21. These two were chosen randomly from the group, but because the trigger was designed to eliminate the influence of PMT noise and random light in the scintillators, any two functioning scintillators will do. The configuration and all aspects of the electronics devices used for this trigger are identical to those used for the CSC test, with 2000 V being supplied to its PMTs.

To perform the test, each scintillator is first stacked on top of the trigger using metal supports. High voltage is supplied to each PMT of the scintillator being tested, while the output signals are passed through the discriminator. Counting the number of output pulses after 10 seconds, I calculated the incidence rates measured by a PMT when supplied with voltages increasing in increments of 50 V from 1100 V to 2300 V. I then repeated the process, this time counting coincidences between the two PMTs of the scintillator. Finally, I set up coincidence between each PMT on the scintillator being tested and the four others of the trigger. Again I calculated the rates for voltages increasing in 50 V increments, but this time, the range was from 1100 V to 2000 V, as I

did not expect to find any interesting features outside this range and wished to avoid wear on the PMTs. At the same time as I measured a coincidence rate between the five PMTs, I also measured the coincidence rate of just the four trigger PMTs. Although the coincidence rates between the PMTs of the trigger remain relatively constant due to the constant voltage applied to them, statistical variation creates a different number each time. The exact number must be paired with the corresponding measurement using all five PMTs so that the efficiency of the PMT being tested can be calculated precisely at that particular voltage.

Unlike the situation with the CSC, the scintillator being tested is the same size as the ones used for the trigger. Therefore, it is not as unlikely that there will be muons that pass through the trigger that do not pass through the test scintillator first. It is expected, then, that the measured efficiency will not reach 100%, but rather level off at a lower value. This does not affect the usefulness of the results as long as we recognize this phenomenon. If we are interested only in the voltage at which maximum efficiency is achieved, then the actual value of the maximum efficiency does not matter.

#### **4. Results**

Of the 24 scintillators tested, I found 23 to at least function. During the testing, I discovered and corrected problems with the voltage dividers of these 23, but these issues were minor and required only light soldering to reconnect wires. Scintillator #4 alone did not work, and its repair was beyond my capabilities.

The plot of the incidence rate measured by each PMT versus the high voltage applied to it shows a very unclear picture of the actual cosmic rays incident on the scintillator. Given that cosmic rays are incident on the earth at about  $1 \text{ or } 2 \text{ s}^{-1} \cdot \text{dm}^{-2}$  and that the scintillators have an area of about  $54 \text{ dm}^2$ , the frequency of particles incident on it should be roughly between  $50 \text{ Hz}$  and  $100 \text{ Hz}$ . However, as the voltage increases, the rate continuously slopes up and up, well past the expected rate. Figs. 3, 4, and 5 show these graphs for scintillators #1, #7, and #18 respectively and their PMTs; the blue and pink plots represent the two PMTs of the scintillator, while the yellow graph is the rate of coincidence between those two PMTs versus voltage. This sloping up in the graphs of incidence rates measured by a single PMT results from both noise in the PMTs and spontaneous light emission by the plastic of the scintillator. By looking at the graphs, we can compare the noise levels in the PMTs. For example, PMT #36 is much noisier than any of the others shown.

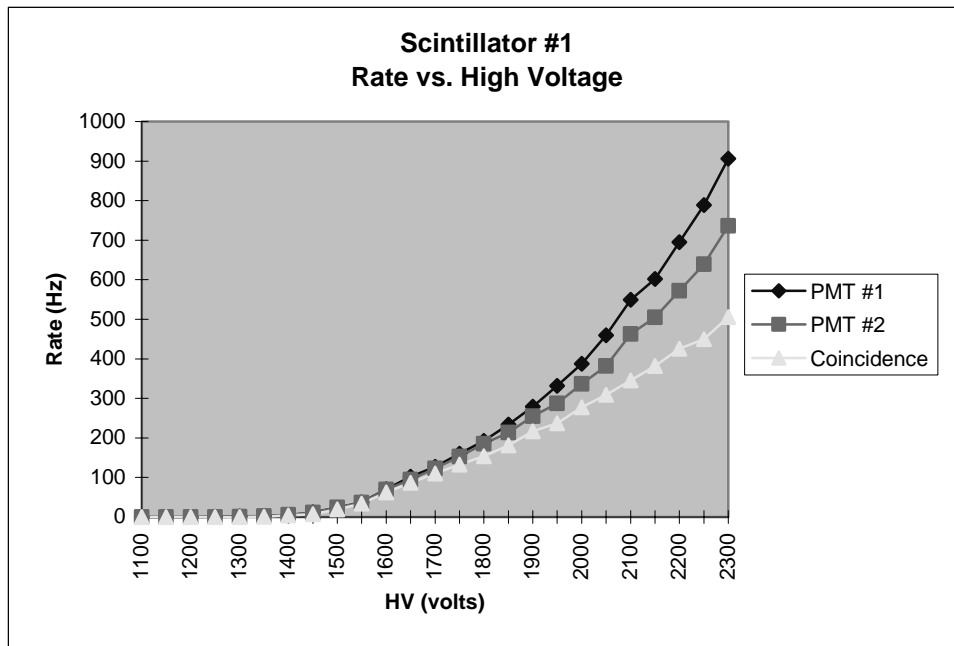


Figure 3. Plot of incidence rates measured by the PMTs of scintillator #1 versus voltage.



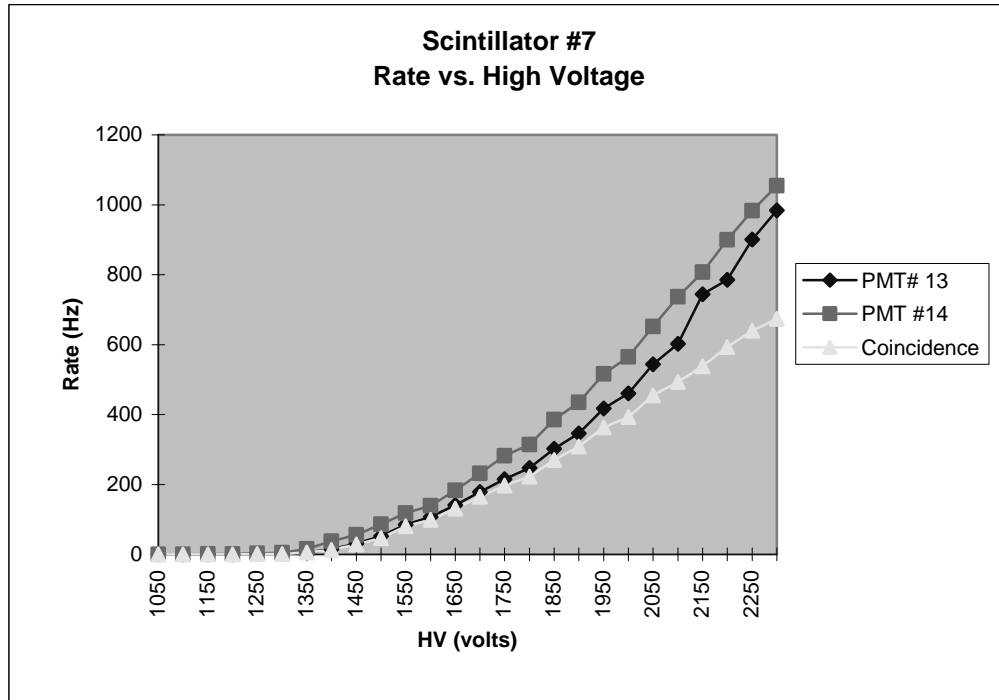


Figure 4. Plot of incidence rates measured by the PMTs of scintillator #7 versus voltage.

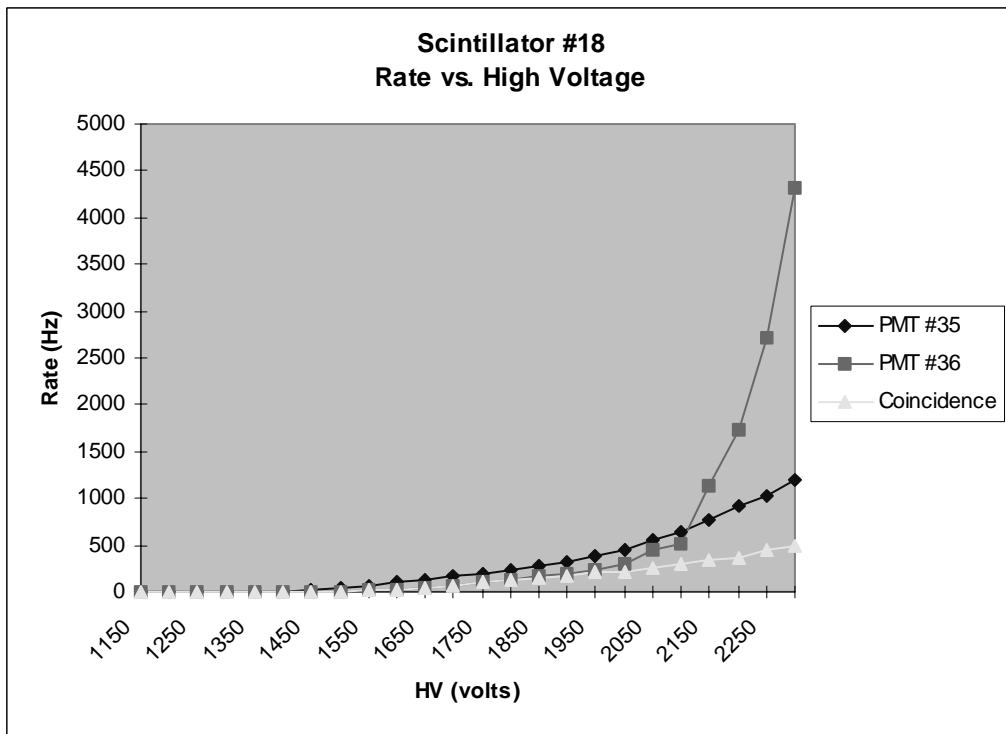


Figure 5. Plot of incidence rates measured by the PMTs of scintillator #18 versus voltage.

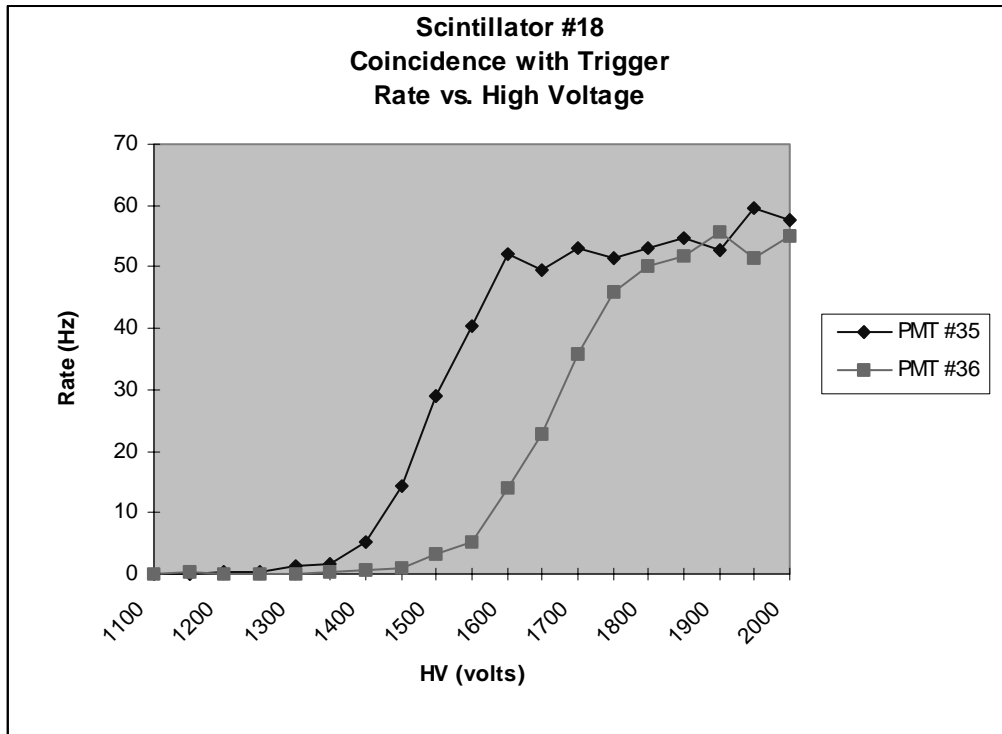


Figure 6. Plots of the coincidence between the PMTs of scintillator #18 with the trigger versus voltage.

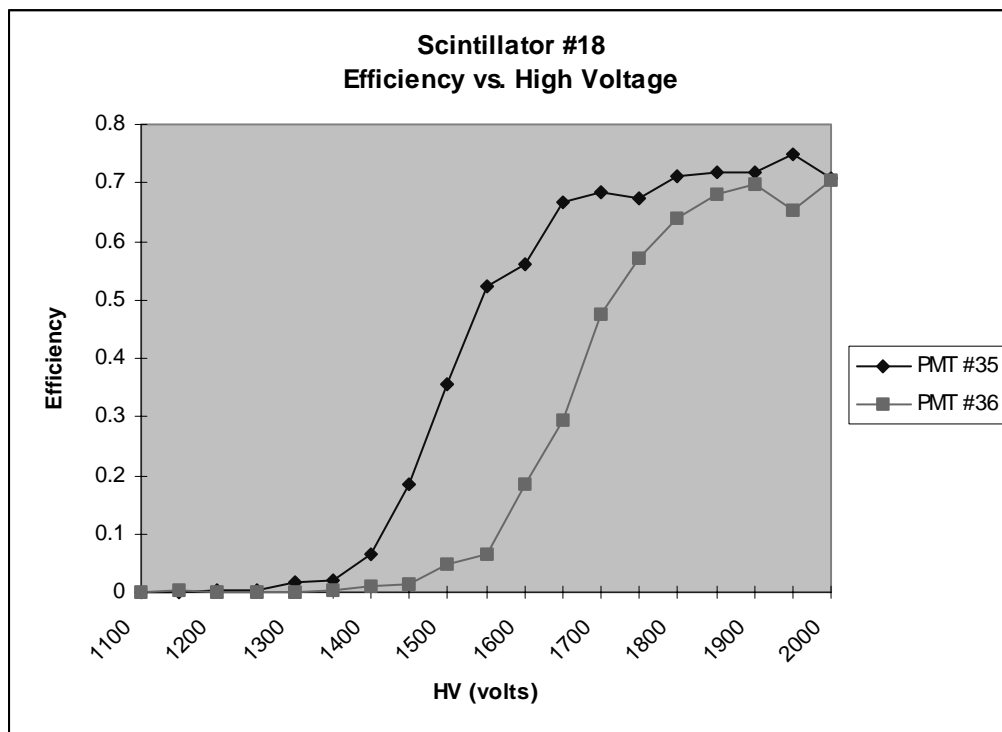


Figure 7. Efficiency of the PMTs of scintillator #18 versus voltage.

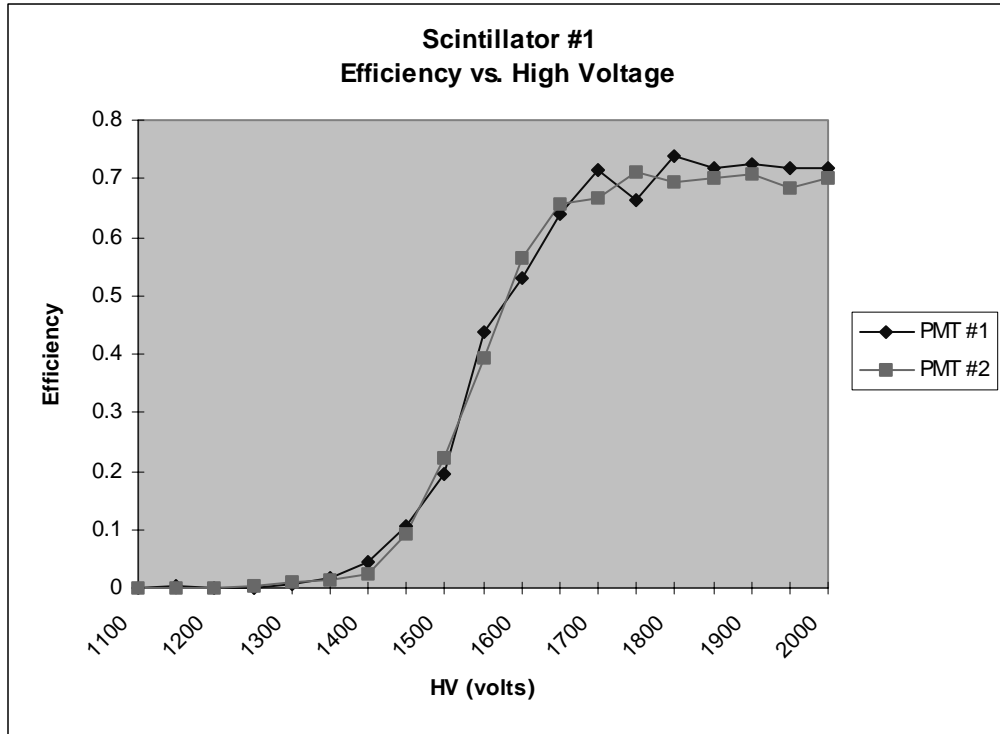


Figure 8. Efficiency of the PMTs of scintillator #1 versus voltage.

Requiring coincidence between the two PMTs of a scintillator should eliminate the effects of random noise, and as we can see in the figures, the value of the coincidence rate is lower than that of the incidence rates of only one PMT in every case. However, these coincidence plots do not level off at expected values either since the spurious light inside the scintillator still remains a factor. Yet, these coincidence plots allow us to compare the influence of this factor in each of the scintillators. The coincidence curve of scintillator #1 is clearly below that of #7. Thus, we can conclude that more random light emission occurs in scintillator #7 than in #1.

Looking at the plots of coincidence between individual PMTs and the trigger, we see that, at last, both noise and spurious light have been eliminated. Fig. 6 shows this graph for scintillator #18. As voltage increases, the coincidence rates level off at values

at the lower end of the range of frequencies where we expect the actual cosmic-ray incidence rate to be. However, we did not anticipate our method to show 100% efficiency in the PMTs.

The measured efficiency of each PMT was also plotted versus voltage. Fig. 7 shows the efficiency graph for scintillator #18 as a typical case. It clearly illustrates that my setup only measures the maximum efficiencies of PMTs #35 and #36 to be about 70%. This result explains the slightly low values of coincidence rates measured using the trigger. Yet the interesting feature of the graph is not the maximum efficiency but the maximum plateau itself and where it begins. The efficiency plots of PMTs #35 and #36 do not level off at the same voltage. While 1750 V looks to be a good value at which to operate #35, #36 does not fully level out until about 1900 V. Therefore, when using this scintillator in the future either both PMTs should be supplied with 1900 V, despite #35's not needing it, or two independent power supply channels should be used. Neither option is very desirable. Thus, it is best to use a scintillator whose PMTs have very similar efficiency curves (see Fig. 8).

## **5. Conclusions**

In summary, I tested 24 BC-408 plastic scintillators<sup>3</sup> along with their PMTs (Philips XP-2212) and produced graphs describing how much noise and spurious light was present in each of them. The graphs also show the efficiency versus voltage of each PMT, from which the optimum operating voltage can be read.

Moreover, I set up a stack of two of the scintillators, which I used both to test the remaining scintillators and to provide a trigger for the testing of CSCs. This trigger relies on coincidence between all four of its PMTs and eliminates both noise and random light in the plastic of the scintillators.

Test of the CSCs so far have involved only one at a time. Ultimately, however, CMS will require the simultaneous coordination of 500 CSCs. Thus, the next step is to develop ways of using two or three CSC at the same time. This is a large and important step. After coordination three CSCs the extrapolation to 500 should not be too difficult.

## **6. Acknowledgments**

I acknowledge and appreciate the knowledge and guidance of Professor Andrey Korytov of the University of Florida. Thanks also to Jay Horton, of the same institution, for his manual and mechanical help.

I would also like to note the financial support of the NSF through the University of Florida REU program.

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