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TECHNICAL REPORT

Discriminating the muon noise at the PMT windows in calorimeters

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Abstract: In particle physics experiments, stray muons are known to be a source of anomalous signals when they produce Cherenkov photons in the PMT window. Most recent of such events were reported by CMS Hadronic Forward calorimeters, where PMTs read out the Cherenkov signal generated within the quartz fibers. This study focuses on finding an efficient way to discriminate the Cherenkov signal coming from the quartz fibers from the ones generated at the face of the PMT due to stray muons. We report that these two different signals can be discriminated based on their pulse widths. The study also shows the performance of a proof-of-concept circuit prototype that effectively tags the two types of pulses.

Keywords: Calorimeters; Photon detectors for UV, visible and IR photons (vacuum) (photomultipliers, HPDs, others); Cherenkov detectors

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Contents

1 Introduction

Cherenkov light generated in the glass envelope of the photomultiplier tubes (PMTs) is a source of anomalous signals in particle physics experiments. Recently Compact Muon Solenoid (CMS) experiment Hadronic Forward (HF) calorimeters reported large anomalous signal when the PMT window is traversed by a relativistic charged particle producing Cherenkov signal [1, 2].

The CMS forward hadron (HF) calorimeter uses steel as an absorber and quartz fibers as the sensitive material. Photomultiplier tubes are used as photon sensors. The two halves of the HF are located 11.2 m from the interaction region, one on each end. They also serve as luminosity monitors. Each HF calorimeter consist of 432 readout towers, containing long and short quartz fibers running parallel to the beam. The long fibers run the entire depth of the HF calorimeter (165 cm, or approximately 10 interaction length), while the short fibers start at a depth of 22 cm from the front of the detector. By reading out the two sets of fibers separately, it is possible to distinguish electromagnetic from hadronic showers [3]. In order to solve the problem of anomalous signals, the CMS collaboration decided to replace all Hamamatsu R7525HA PMTs [4] that have a thicker front window with 4-anode, thin window Hamamatsu 7600U200-M4 PMTs [5]. This replacement reduced the size and rate of the anomalous signals, as well as providing the ability to tag the anomalous signal events by using the multiple anode feature. However, replacing 1800 PMTs, and adding multi-anode readout capabilities was a costly option.

Previous studies focused on the signal arrival times differences value between the real and anomalous signal events, which may or may not be effective depending on the experimental conditions. This study shows the evidence for a very clear pulse width difference between the Cherenkov signal coming from the quartz fibers and the one generated at the front window of the PMT. These timing differences help to discriminate the anomalous signal using a simple circuit. Test results of a proof-of-concept prototype circuit are reported in this study. This approach could provide a more cost-effective option for future experiments.

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2 Experimental setup

The pulse width of the events, due to muon interaction at the front window of Hamamatsu R7525-HA PMT, have been investigated with a 150 GeV muon beam at CERN H2 beam line. For mimicking the anomalous signal events the PMT, inside a light tight box, was positioned facing the muon beam. The gain of the PMT was set to 10^6 with 1500 V high voltage value and each triggered signal was recorded by a digital oscilloscope. More than 719 such events were recorded.

The CMS HF Calorimeter signal was mimicked by using a 2 m long quartz fiber bundle with 1 cm diameter. The setup utilized 80 GeV electron beam at CERN, and 5 cm iron absorber to create an electromagnetic shower. A small portion of the fiber bundle has been carefully positioned behind the absorber to capture the showering particles after the 5 cm iron absorber. As the showering charged particles pass through 600 μm core of the quartz fiber, the Cherenkov photons are created and travel along the length of the fiber, imitating an HF tower. The other end of the fiber was positioned 1.5 m away from the beamline, and attached to a 42 cm air-core light guide, the same as the ones used in CMS HF calorimeters. Total of 4650 events were detected by the Hamamatsu R7525HA PMT attached to the other end of the light guide.

Figure 1 demonstrates the clear difference between the pulse shapes of the muon interactions in the PMT window and the Cherenkov signal carried by the quartz fiber bundle. Five sample pulse shapes plotted in figure 1 left shows that at FWHM the muon interactions with the PMT window yield 1.6 ns pulse width. Although the amplitudes of the events vary, the width and shape of the pulses are almost identical. Here, it should be emphasized that the tests with cosmic muons yield the same symmetrical pulse shape with less than 2 ns width. The overlapped scope view of five sample Cherenkov signal carried by the fiber bundle are given in figure 1 right. Unlike the muon events, a typical Cherenkov signal from quartz fibers is asymmetrical with sharp fall time, and a longer tail on rise time. Again, the amplitudes of the events vary, but the pulse shapes are the same, and the FWHM values are consistently between 4 ns and 5 ns.

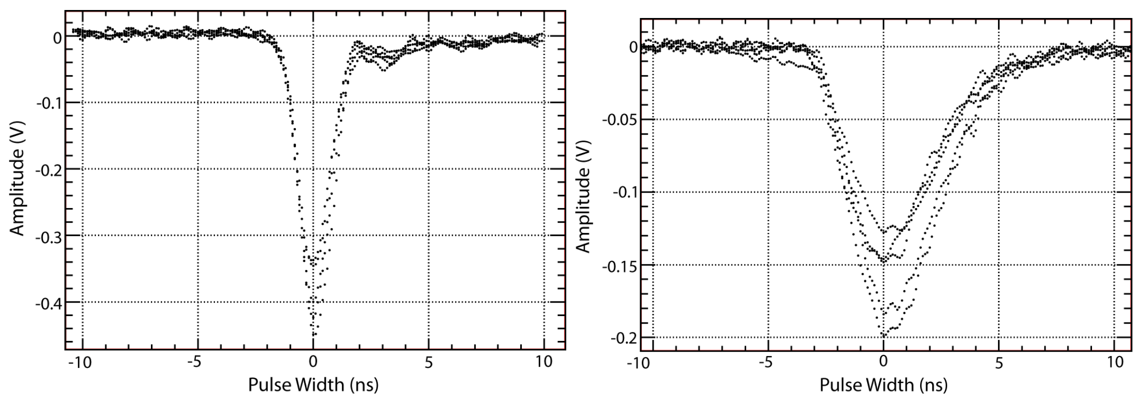

Figure 1. Overlapped scope views of five events created by muons interacting on the window of PMT [left]. Overlapped scope views of five Cherenkov signals created at the quartz fibers [right].

The pulse width analysis of all events recorded during the CERN test beam are given in figure 2. The pulse width distribution for the 719 muon events at PMT surface yields a mean value of 1.6 ns with all of the events having narrower than 2 ns pulse width. Figure 2 right shows the pulse width distribution of the 4650 Cherenkov events collected by the fiber bundle. These events' pulse width distribution yields a mean value of 4.5 ns. with no event having less than 3.8 ns pulse width.

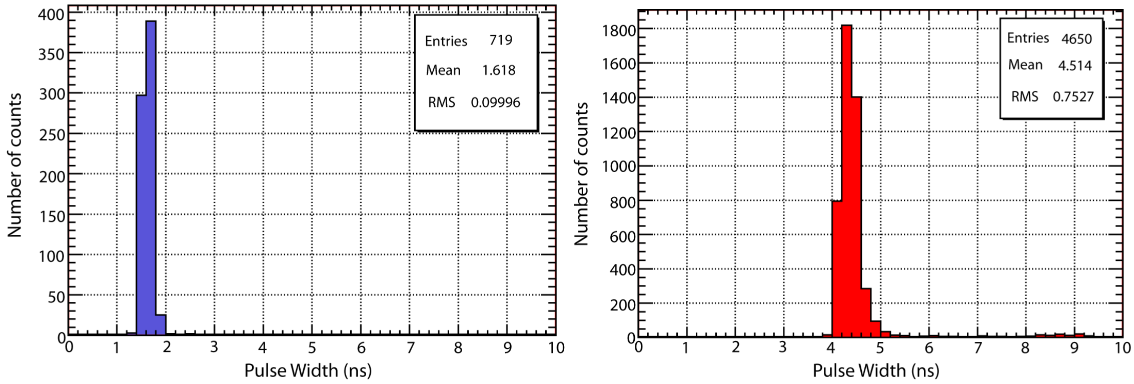

Figure 2. Measured pulse width distribution of over 700 events from muons interacting with the front window of HF PMTs [left]. Measured pulse width distribution of over 4600 Cherenkov signals created at the quartz fibers [right].

3 Anomalous signal tagger circuit

Since the pulse width difference between these two types of events is very discriminating, a simple tagging circuit may be attached to PMT readouts. A proof-of-concept circuit was designed and built at the University of Iowa laboratories. The circuit measures the length of each pulse by using a charge pump (see figure 3). If the pulse width is shorter than some value the circuit has the capability of tagging (or blocking) the event. For the specific example given above, the threshold is set to 2.5 ns.

The performance of the pulse width discriminating circuit was tested at Coe College laboratories. Nitrogen laser (337 nm) light was injected into a dark box via a fiber in order to mimic the signal coming from the HF calorimeter (see figure 4). The laser pulse was set to yield 3 ns width by a wave generator, and a Hamamatsu R7525HA PMT was used to detect the signal. The cosmic muons hitting the face of the same, upward positioned, PMT were used to imitate the muon events on the surface of the PMT. The PMT pulse widths were recorded for both muon and laser events. Figure 5 shows the pulse width distribution of the cosmic muons (left) and the laser events (right).

By comparing figures 1 and 5 one can clearly see that the test setup successfully reproduced the typical pulse width differences between the cosmic muon and the laser events as observed in beam tests.

At this point, the PMT signals, with amplitudes between 200 mV and 300 mV, were directed to the circuit to be flagged based on the pulse width. The circuit event flag threshold was set to 2.5 ns pulse width, and the laser frequency was varied between 1/30 Hz and 25 Hz.

Figure 6 shows that the prototype circuit successfully tags all the events with higher than 2.5 ns pulse width. The circuit effectively discriminates the events based on pulse widths. The efficiency to tag the events with higher than 2.5 ns pulse width is 100% (651 out of 651). The mistag efficiency, the ratio of the number of anomalous signals that pass the selection divided by the total number of anomalous signals, was found to be 0.3% (3 out of 880).

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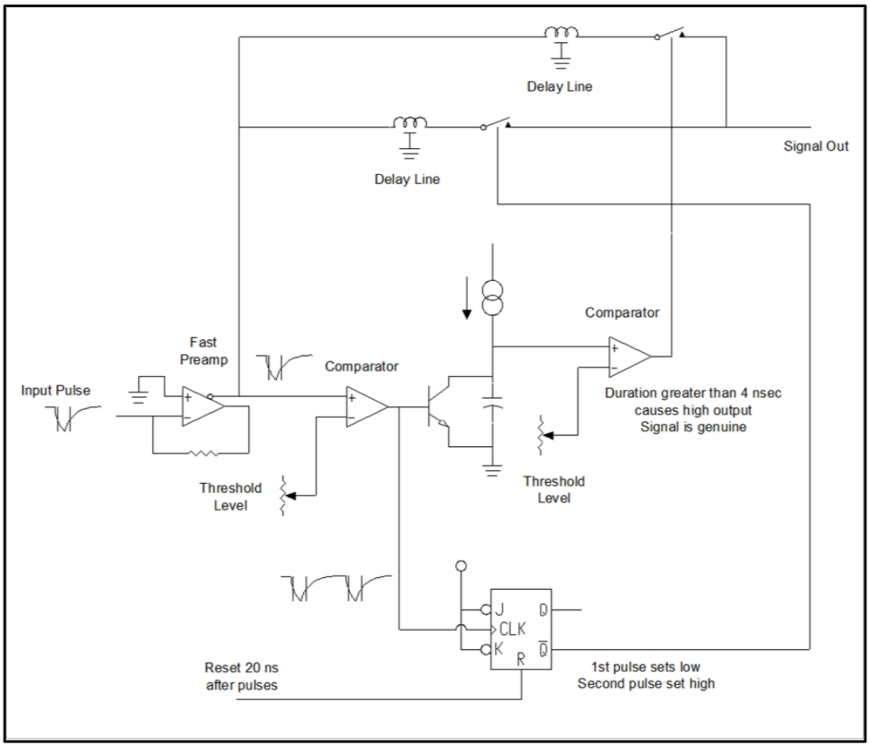

Figure 3. Circuit diagram of the proof-of-concept pulse width discriminator.

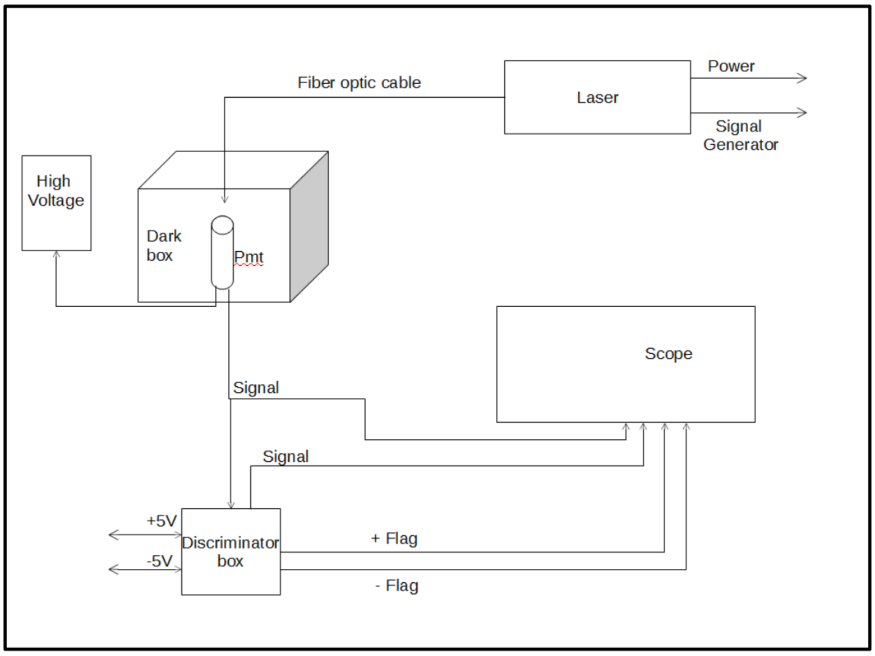

Figure 4. The schematics of the setup used to test the performance of the pulse width discriminator prototype.

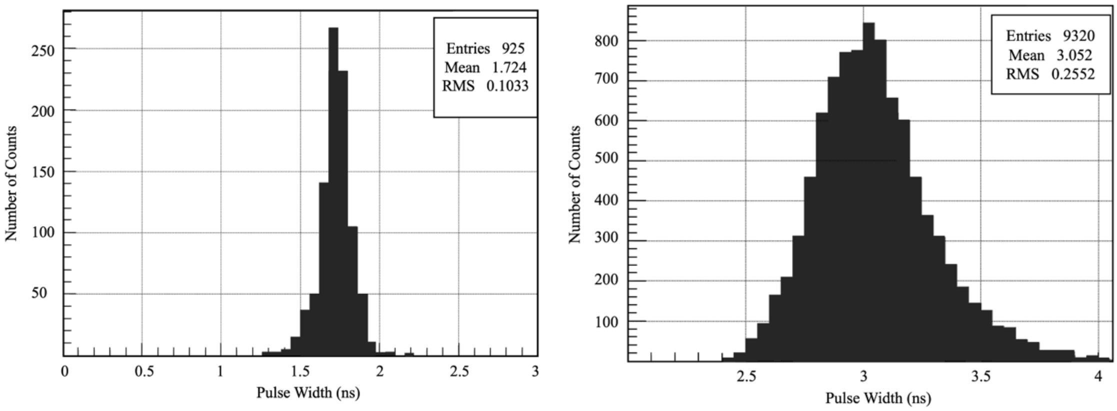

Figure 5. The pulse width distribution of the cosmic muons interacting with the front window of the PMT [left]. The pulse width distribution of the laser pulse injected into the dark box via fiber [right].

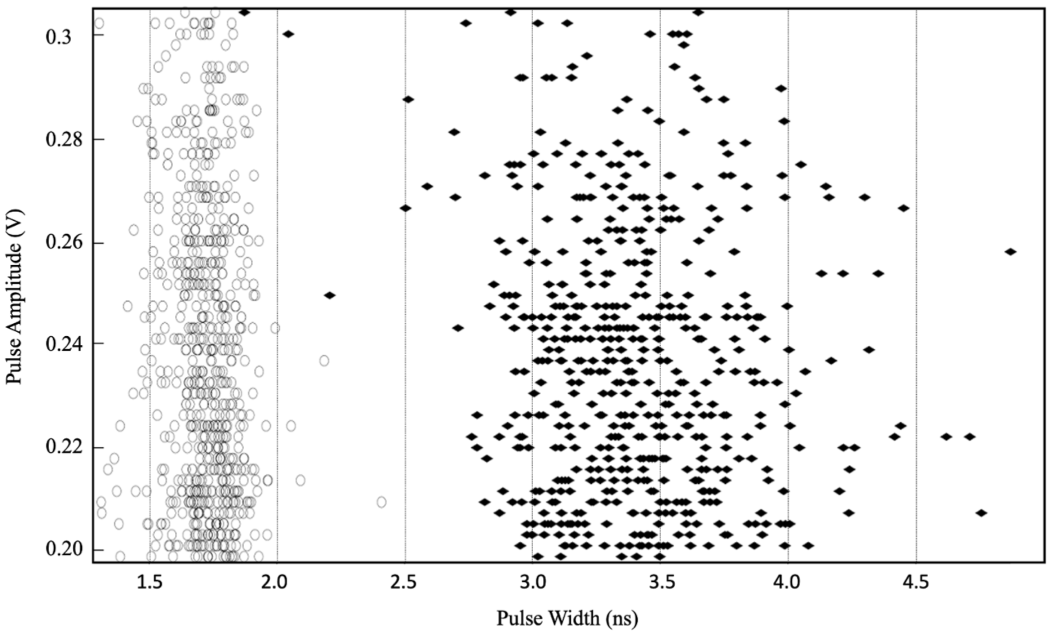

Figure 6. Pulse amplitude versus width for the events during the circuit performance tests. The black diamond labels show the events that are flagged as good by the circuit, while the open circles are those which are flagged as anomalous signal.

4 Conclusion

The PMTs are built with glass windows, and they are prone to produce anomalous signals during particle physics experiments due to stray muons. These charged particles could be originated at the collision point or they can be cosmic muons. Strategic positioning of the readout box behind the shields would reduce these anomalous signal events, but cannot completely eliminate them. CMS HF calorimeters, which are designed to detect the Cherenkov signal within the quartz fibers, reported such anomalous signal events and solved the problem by replacing all Hamamatsu R7525HA PMTs with a thin window, 4-anode PMTs.

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This study used a setup with Hamamatsu R7525HA PMTs, quartz fibers, and light guide similar to the CMS HF calorimeter. The results show that there is an unmistakable pulse width difference between the Cherenkov radiation generated at the front window of the PMTs due to muons and the Cherenkov signal delivered by the quartz fibers. Over 4600 collected events confirm that the regular Cherenkov signal carried in quartz fiber has an asymmetrical pulse shape with at least 4 ns width. On the other hand, the Cherenkov signal created by the charged particle interacting with a borosilicate glass window of Hamamatsu R7525HA PMT has a symmetrical, sharp pulse with less than 2 ns width.

This study also demonstrates that a simple circuit can tag such events effectively. A simple electronic circuit has been designed to discriminate between real physics signals and anomalous signals exploiting the pulse width difference among them. The circuit was produced and tested using a laboratory setup with laser light and cosmic muons to mimic the real calorimeter signals and the anomalous signals. The circuit effectively discriminates the two types of pulses. The efficiency to tag the events with higher than 2.5 ns pulse width is 100%, while the mistag efficiency was found to be 0.3%.

Acknowledgments

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