PROCEEDINGS OF SCIENCE

Trigger Strategies in TRIDENT using hDOMs

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TRoplcal DEep-sea Neutrino Telescope (TRIDENT) is a next-generation neutrino telescope planned to be constructed in the South China Sea. It incorporates a hybrid digital optical module (hDOM) that combines both photomultiplier tubes (PMTs) and silicon photomultipliers (SiPMs). Overcoming the challenge of minimizing ambient backgrounds such as ^{40}K and dark noise captured by the photon sensors necessitates the use of trigger mechanishm. In this study, we propose a triggering algorithm that relies on implementing temporal and spatial coincidence criteria within hDOMs, and this work jumpstarts the full TRIDENT trigger schemes, which are to be developed and validated in the coming years.

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1. Introduction

TRopIcal DEep-sea Neutrino Telescope (TRIDENT) will be deployed on the abyssal plane at South China Sea to discover high-energy astrophysical neutrino sources and provide great opportunities for particle physics research by measuring neutrino of all flavors [1]. The telescope will employ a Penrose geometry layout with about 1200 strings and 24000 hybrid Digital Optical Modules (hDOM) [2] covering a volume of about 7.5 cubic-kilometer. The fundamental detection unit hDOM will utilize state-of-art technologies, including multiple 3-inch PMTs and SiPM arrays. The telescope's design performance is remarkable, while backgrounds such as K40 and dark noise from the PMTs can result in significant triggers that may overflow the data transmission bandwidth and cause computational problems. In this study, we will describe a trigger strategy using TRIDENT hDOMs to mitigate this problem, and the trigger scheme under further development and optimization for TRIDENT is also described.

2. Trigger Scheme

The trigger is based on the distinct temporal and spatial characteristics of signals from PMTs. Noise consists mainly of uniformly-distributed random photons, whereas signals typically have unique space-time correlations as multi-photon clusters. Given that the total data rate without any trigger can reach up to 12Gbps per hDOM which is dominated by backgrounds by several orders of magnitude, a dedicated trigger scheme is needed in TRIDENT's data acquisition.

The main objective of the trigger is to reduce ambient noise while retaining the desired physics events. The initial stage of our trigger system is implemented on the FPGA within the hDOM, known as the hDOM trigger. This component relies exclusively on the PMTs since the SiPMs have a relatively high dark count rate, approximately on the order of 10^6 counts per second (cps). The PMT signals are stored in an analog buffer. Once the FPGA confirms that the coincidence criteria has been met, PMT or SiPM signals are then digitized and transmitted via the seafloor composite cable to the DAQ system. Specifically, the coincidence threshold for a single hDOM is defined as n PMTs or photons within a τ ns time window. Typically, n is an integer greater than one, and τ is approximately ten nanoseconds. The most commonly used parameter pair of (n, τ) in our context is $(2, 10)$.

The next step is online filtering and processing. By analyzing the coincident photons in nearby hDOMs, a localized cluster is formed. This cluster typically consists of multiple hDOMs within a cylindrical or spherical space, selected from a total of about 24000 hDOMs. This localized cluster effectively encompasses potential track events or cascade events, allowing for a more focused analysis with more information. Two steps are outlined in Figure 1.

The design of the trigger system requires careful considerations of both physics needs and engineering practicality. Trigger selection in the sea is expected to be simple and robust, while most physics filters and particle identifications will be performed on the computation station located on the shore.

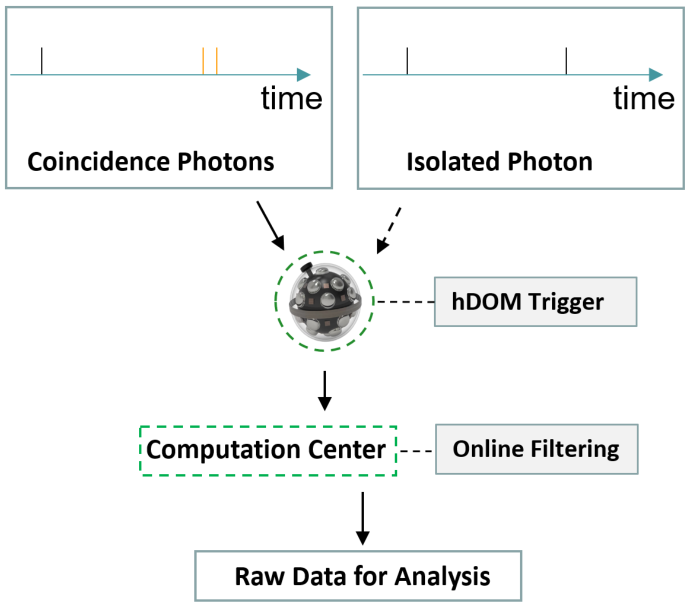

Figure 1: The flow chart of TRIDENT trigger system. The data flow generally is mono-directional.

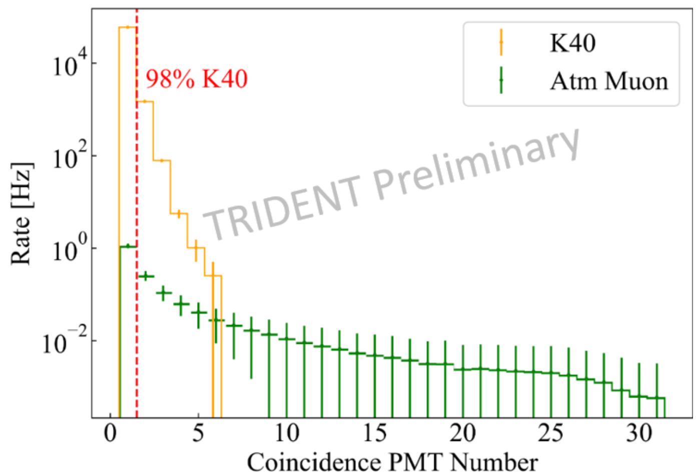

Figure 2: As the coincidence level increases, the photons gradually increase from ^{40}K domination to atmospheric μ domination. This feature guides our design of the hDOM trigger.

3. hDOM Trigger

The most significant background for our hDOMs are from dark noise and ^{40}K. The triggering of an hDOM occurs when two or more PMTs are hit within a 10 ns time interval. In such cases, both SiPM information and PMT waveform data are collected. This section's main focus is to assess the hDOM's effectiveness in reducing bandwidth from dark noise and ^{40}K. Bandwidth before and after implementing trigger are estimated as the first step of hardware system design in the Table 1, ensuring that the system can handle the volume of data generated by the detection array. As for dark noise specifically, we calculate the data rate by assuming its uniform distribution.

Table 1: The data bandwidth estimation before and after hDOM trigger

Event type	Bandwidth (no trigger)	Bandwidth (hDOM trigger)
dark noise	270MB/s	10B/s
K40	1.50GB/s	<40MB/s

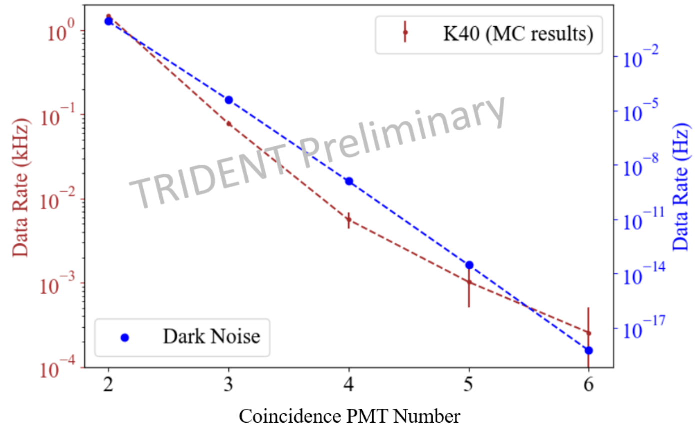

Figure 3: Raising the coincidence number threshold results in a noticeable decrease in the data rate.

For TRIDENT detector, ^{40}K decay is a significant source of noise, and it is vital to comprehend how hDOMs respond to it. According to previous simulations [1], Cerenkov photons from the gamma-ray or the electrons generated in the decay will induce busy activities in the hDOM. For instance, with 31 PMTs in one hDOM surrounded by 10.87Bq/L ^{40}K decay, the average noise rate per PMT is $\sim$ 2.0 kHz. This generates a Giga-Byte level of background for TRIDENT detector, which imposes great challenge for data taking. If there is no coincidence criteria for hDOM, the data flow's bandwidth will be overwhelmed by the isolated photons generated from ^{40}K decay. Another source of noise in PMT is dark noise, which is around 300 Hz. Multiple PMTs inside hDOMs superpose their dark noise linearly. Their bandwidth should also be suppressed.

The simulation indicates that the ^{40}K event rate drops by roughly two orders of magnitude after hDOM trigger processing. In Figure 3 and Figure 4, the data rate induced by coincidence hits from ^{40}K and dark noise are presented. These results along with the bandwidth estimation in table 1 indicates that the parameter pair (n, τ) can be chosen as $(2, 10)$. In Figure 2, the hDOM response of both the ^{40}K and the atmospheric muon are featured with the coincidence PMT number. Setting coincidence criteria can reduce the ^{40}K data rate and gradually increase the significance of signal photons.

4. Summary and Outlook

In these proceedings, a preliminary trigger scheme for TRIDENT using the hDOM is introduced, which consists of two steps. The first step involves the hDOM trigger, the waveform will be

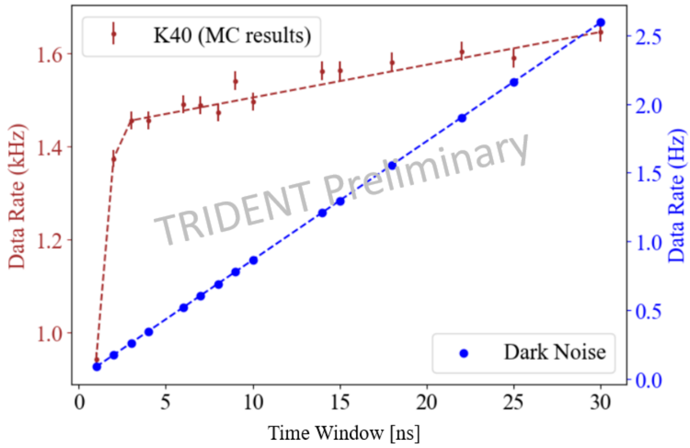

Figure 4: Modifying the time window after 10 ns does not have a significant impact on the data rate.

readout only when there are coincidence of PMT hits within an hDOM. By suppressing the bandwidth from isolated photons, this approach saves significant bandwidth from noise. The second step involves online filtering and processing at computer farms, which will be developed in the future together with a proper evaluation of trigger efficiency. More detailed trigger design structures will be developed and evaluated in subsequent work.

References

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